The Town Lake Report Update, 2006.

Chris Herrington
Water Resource Evaluation Section, Environmental Resource Management Division,
Watershed Protection & Development Review Department, City of Austin

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Acknowledgments

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1.0 Summary of Findings

This report is an update on the current condition of Town Lake, primarily focusing on data collected from 2000 to 2006 and building on the work of previous City of Austin analyses (COA 1992, COA 2001). Recommendations for changes in assessment strategies resulting from this analysis are included with each topical section.

Population and the number of building permits issued within the Town Lake contributing drainage areas downstream of Lake Travis continue to increase due to suburban expansion and urban infill. Residential and transportation land use in the Lake Austin adjacent watersheds are increasing over time at the expense of open space, although percent residential land use has actually decreased over time in the Town Lake adjacent watersheds.

Town Lake continues to be of concern for nitrate/nitrite according to Texas Commission on Environmental Quality (TCEQ) screening levels. Low dissolved oxygen (DO) concentrations continue to be problematic at the Basin, particularly from August to October. Although the aerial extent cannot be evaluated, the percentage of the water column at the Basin experiencing low DO conditions may be increasing over time. The recent temporal decline in DO at the First Street site appears to be independent of change in temperature. Comparison of site differences, DO-depth profiles and temperature-depth profiles indicate that DO dynamics in Town Lake are potentially more related to biological oxygen demand and production and less related to temperature.

Town Lake water quality continues to be spatially heterogeneous. Discharges to Town Lake from the City of Austin degrade the water quality of the Colorado River. The effects of the Austin's urban downtown watersheds and Barton Creek on Town Lake are evident in the longitudinally increasing concentrations of ammonia, bacteria, sulfate and total suspended solids (TSS), and decreasing clarity (Secchi disk depth). Peaks in surface nitrate and total nitrogen at the First Street site are most likely due to elevated nitrate discharged from Barton Springs.

Water quality may be improving over time in Town Lake for metals, dissolved solids, ammonia, total Kjeldahl nitrogen (TKN), total nitrogen, orthophosphorus and phosphorus. Despite decreasing nutrients, chlorophyll-a over the period of record is increasing over time, although the trends are not significant for data collected since January 2000 suggesting that the system is relatively stable at present. Increasing clarity or increasing algal biomass loading from Lake Austin could drive the observed long-term increasing chlorophyll-a in Town Lake (and subsequent decreases in nutrient concentrations). If algal growth patterns continue to change, the impacts of algal biomass on Town Lake (particularly for DO) can be expected to change correspondingly.

Ambient sediment samples from Town Lake continue to yield contaminant levels potentially toxic to aquatic life for PCB, DDE, metals and PAHs. Cadmium and lead are decreasing over time in Town Lake sediments. Lead in Town Lake sediments is probably from anthropogenic sources. Anthropogenic sources may also contribute to arsenic, cadmium, chromium, mercury, and zinc in Town Lake sediments. Anthropogenic sources of metals to Town Lake may be decreasing over time. Although Town Lake sediments are generally higher in metals, creek sediments have higher concentrations of PAH and PCB.

Despite an observed reduction in metals, there are no significant temporal trends in PAHs or PCBs. Concentrations of some organochlorine pesticides in sediments, including chlordane and DDT, may be decreasing over time. The absence of an increasing trend in PAH considering the continued increasing population and traffic volume may actually reflect a decrease in PAH over time.

Based on Visual Index of Pollution (VIP) scores, Town Lake is not degrading aesthetically. Current litter management practices are sufficient to maintain acceptable lake-wide VIP scores at current levels of litter deposition. The southern shore of Town Lake near IH-35 yields the worst VIP scores, although some of these areas are improving over time.

Less impaired benthic macroinvertebrates metric scores are generally observed during the release season. Town Lake benthic macroinvertebrates may be more stressed at the end of the winter/spring low-flow non-release season despite cooler temperatures. There are few differences between metric scores at the sampling locations. Observed differences are most likely due to riparian habitat differences, but could indicate impairment at the IH-35 site with recovery at the Basin site.

Lake Austin continues to maintain higher baseline algae concentrations, particularly during the release season when Town Lake algae counts are at a minimum. For the majority of the period of record Town Lake is in an oligotrophic state for at least 50% of the year based on monthly median counts, although recent data from 2005 and 2006 were more enriched and primarily mesotrophic.

Flagellate algae bloom frequency is decreasing over time but there are no trends in the percentage of time that Town Lake is in the oligotrophic or mesotrophic states based on the total AWU plankton counts. Although Carlson Trophic State Index values indicate that Town Lake is becoming more eutrophic when the entire period of record is considered, TSI values show an improvement (less eutrophic) using only data collected since January 2000.

Long duration algae blooms typically are comprised of blooms of multiple algal divisions. DO impairments from algae blooms may be partially mitigated or amplified by other factors such as antecedent flow or ambient temperature. Green algae and diatoms are more likely to bloom in any given year than blue-green or flagellate algae.

As expected from historical analyses, Town Lake is more eutrophic at the Basin and First Street sites during the non-release season than at Red Bud. Improvements in Town Lake clarity from improved structural and non-structural best management practices could actually increase Town Lake algal growth at current nutrient levels. Town Lake phytoplankton growth continues to be primarily phosphorus-limited.

A Town Lake Index, similar to the City of Austin Environmental Integrity Index, is proposed based on variably-weighted components drawn from historically consistent Town Lake data sources including phytoplankton trophic status, water quality, sediment quality, aesthetics, and benthic macroinvertebrate community integrity. Using the proposed index, the average Town Lake Index score for the period of record is 66, and is in the “good” category on the EII classification scale.

2.0 Current Setting

Land use and Population
For GIS analyses, the adjacent contributing drainage areas of Town Lake were divided into three zones (Table 2.1, Figure 2.2).

Table 2.1. Percent of area in GIS analysis zone.

GIS Zone	Description of Area	% of Total Area
Town Lake	Town Lake contributing areas downstream of Lake Austin including the lower half of the Barton Creek watershed in the City of Austin ETJ	34.6
Lake Austin	Lake Austin contributing areas downstream of Lake Travis and upstream of Town Lake	44.0
Upper Barton Creek	Upper half of the Barton Creek watershed upstream of City of Austin ETJ	21.4

Decennial census data were used to calculate population within the zones for 1980, 1990, and 2000 (Table 2.2). Housing starts information was used in conjunction with household size figures to estimate year 2007 ("as of" January 2007) population.

Table 2.2. Annualized growth rate in the Town Lake contributing drainage areas (downstream of Lake Travis).

Period	Annualized growth rate (%)
1980 – 1990	1.9
1990 – 2000	2.5
2000 – 2007	1.1

Population within the Town Lake watershed has increased substantially since 1980 (Figure 2.1). The annualized growth rate during the 1980s was 1.9% as almost 40,000 new residents were added to the watershed. Much of this growth resulted from new suburban housing stock built within the Bull Creek, Lake Austin, Bee Creek, and Barton Creek watersheds. However, the largest surge of new population came during the 1990s when more than 60,000 new residents were added. The Panther Hollow, Bear Creek West, Steiner Creek, Lake Austin and Barton Creek watersheds witnessed vigorous levels of housing stock expansion.

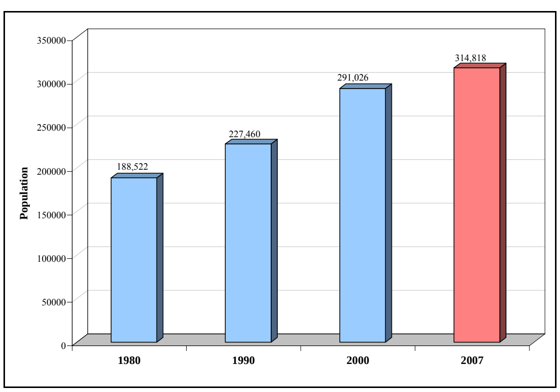


Figure 2.1. Town Lake and Lake Austin adjacent contributing watershed population history.

Population growth during the first seven years of the 2000s has slowed compared to previous periods, although more than 20,000 new residents have been added to the watershed. Continued suburban expansion along with urban infill housing will propel the watershed's population for the near future. The far western portions of the watershed (Barton Creek) could experience tremendous population growth in the future as a result of new water availability.

Trends in Austin-area water quality have been correlated to patterns in construction (COA 1996). City of Austin building permit data (www.ci.austin.tx.us/growth) from 1991 to 2006 for new structure construction only (as determined by permit usage code) was clipped to Town Lake and Lake Austin contributing watersheds within the City of Austin ETJ boundaries to generally represent new construction relevant to Town Lake contributing drainage area in Austin (Figure 2.2). Construction not permitted by the City of Austin, including construction in the Travis and Hays County unincorporated areas to the west of Town Lake in the Barton Springs watersheds, is not included and could affect any predictive analysis. Data from other entities should be integrated once it becomes available.

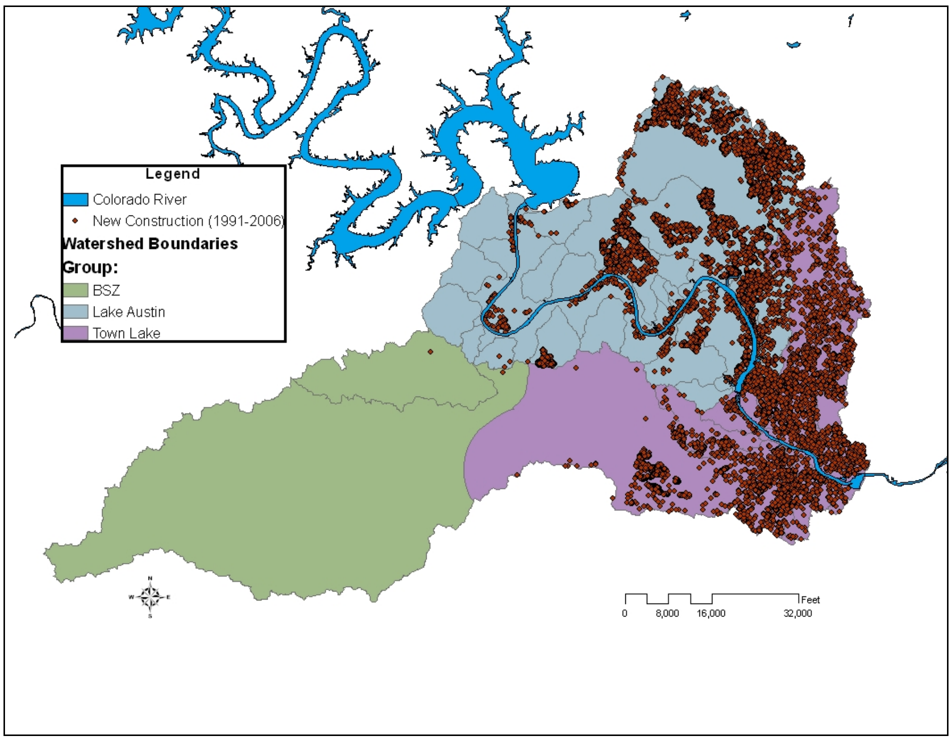


Figure 2.2. Building permits issued by the City of Austin for new construction from 1991 to 2006.

The population expansion in the Lake Austin watershed during the 1990s mirrors a peak in the total number of building permits issued (Figure 2.3), although the number of permits issued in the Town Lake adjacent contributing watersheds has exceeded the number of permits in Lake Austin since 2004. Both Town Lake and Lake Austin contributing watersheds experienced a peak in building permits in the mid to late 1990s; a second sharp increase was observed in Town Lake in 2005. The number of permits issued by year is increasing over time in the Town Lake watersheds, but decreasing over time in the Lake Austin watersheds. The increase in Town Lake building permits is observed in both residential and civic/commercial permits.

The total square footage of building permits issued in Town Lake contributing watersheds has increased over time, and has consistently exceeded Lake Austin building permit square footage since 2000. Within the Town Lake contributing watersheds only, the number of residential permits consistently exceeds the number of other types, although the total square footage of commercial permits exceeded the area of residential permits from 1998 to 2003 and again in 2006 (Figure 2.4). Commercial building permits, however, may not accurately reflect construction area and should be normalized by vertical height in the future.

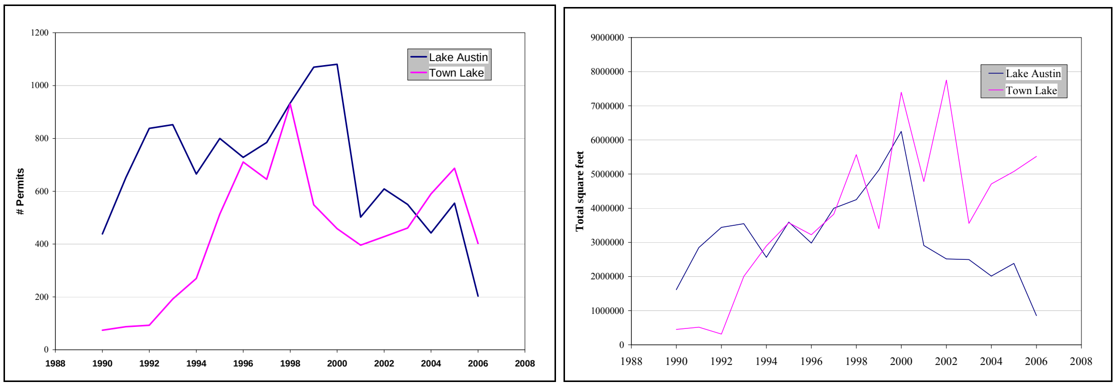


Figure 2.3. Total number and area (square feet) of building permits in the Town Lake and Lake Austin contributing drainage areas by year.

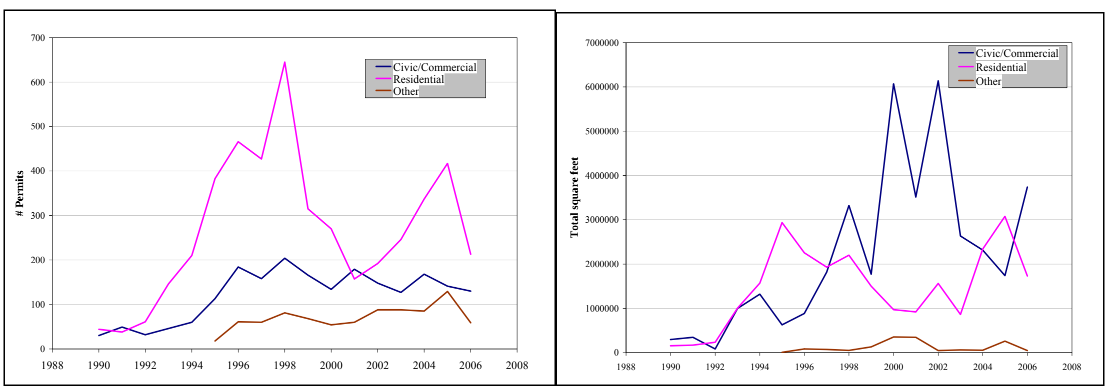


Figure 2.4. Total number and area (square feet) of building permits by general type of permit for the Town Lake contributing watersheds only.

Land use information for the Town Lake adjacent contributing area is available from 1990, 1995, 2000, and 2003, although the land use of at least 20% of the area of the upper Barton Creek zone was generally unknown until 2003. Open space in the Lake Austin and upper Barton Creek zones and residential in the Town Lake zone dominate the land use of Town Lake in the Austin area (Figure 2.5). The areas of unknown land use restrict the usefulness of temporal trend analysis, particularly in the upper Barton Creek zone (Table 2.3). Residential and transportation land use in the Lake Austin zone are increasing over time at the expense of open space, although percent residential land use has actually decreased over time in the Town Lake zone. Large-scale future development and associated non-point source contamination is more likely to occur in the larger percentages of open space in the Lake Austin and upper Barton Creek zones.

In an attempt to reduce the amount of unknown area in the upper Barton Creek zone, the 2003 open space was assumed to be a minimum for all previous years and the 1990 residential use was assumed to be a minimum for all following years. Temporal trends in the total Town Lake area land use was reassessed using adjusted upper Barton Creek zone percentages. Only the open space use exhibited different results. Open space land use in the total area yields a decreasing trend over time (Pr>F reduced from 0.55 to 0.05; r^2=0.89, estimate=-0.39%/year).

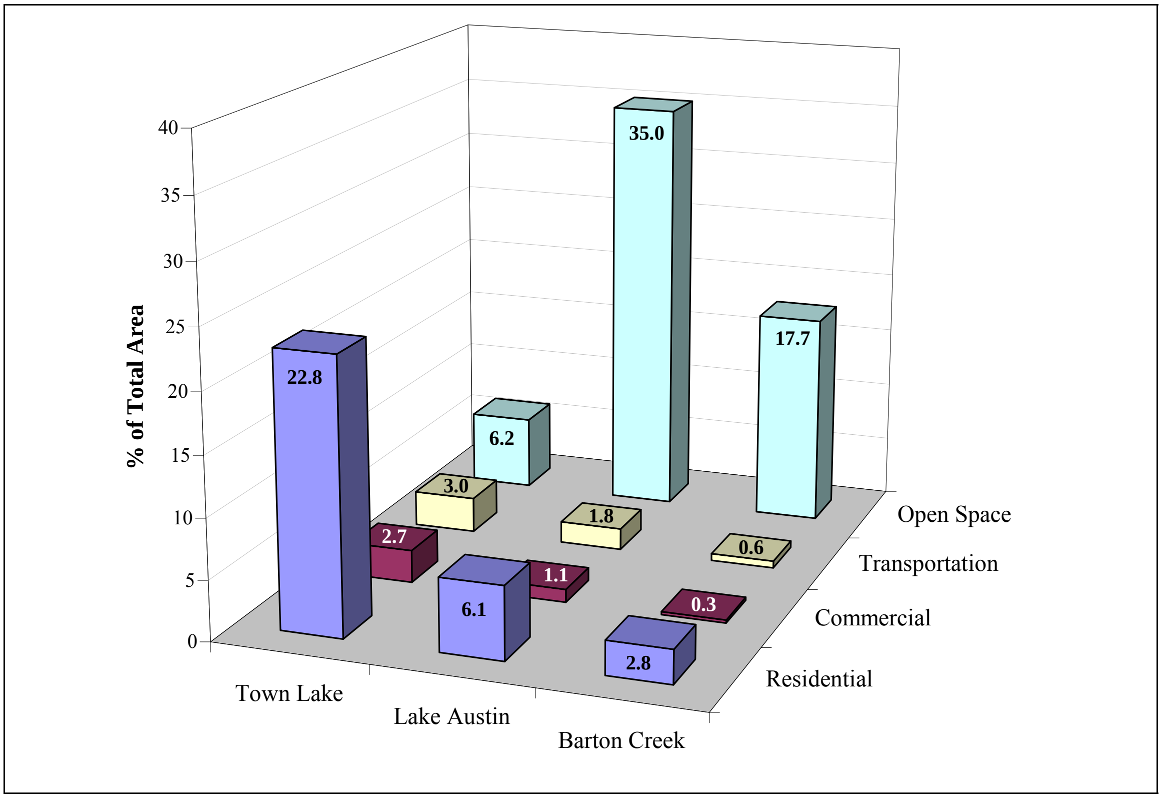


Figure 2.5. Land use categories by zone as percentage of total area for year 2003.

Table 2.3. Change in percent land use by category over time for total area and by individual zone with linear regression statistics before adjustment.

Land Use	1990	1995	2000	2003	Pr>F	r^2	Estimate (%/yr)
Total Area							
Residential	27.49	28.03	28.69	31.64	0.136		
Commercial	3.28	3.46	3.91	4.06	0.015	0.97	0.06
Transportation	0.21	1.82	3.31	5.34	0.016	0.97	0.38
Open Space	62.84	55.64	58.03	58.96	0.546*		
Unknown	6.18	11.05	6.06	0.00	0.392		
Town Lake zone only							
Residential	67.46	66.55	65.59	65.76	0.047	0.91	-0.14
Commercial	7.72	7.47	8.21	7.85	0.480		
Transportation	0.45	2.86	5.54	8.55	0.012	0.98	0.60
Open Space	21.37	20.14	17.69	17.84	0.035	0.93	-0.30
Unknown	3.00	2.98	2.97	0.00	0.294		
Lake Austin zone only							
Residential	8.76	10.92	12.66	13.81	0.001	1.00	0.38
Commercial	1.30	1.87	2.30	2.47	0.008	0.98	0.09
Transportation	0.08	1.89	3.11	4.10	0.003	0.99	0.30
Open Space	88.73	81.62	80.82	79.63	0.088	0.83	-0.65
Unknown	1.13	3.70	1.11	0.00	0.554		
Upper Barton Creek zone only							
Residential	1.29	0.84	1.94	13.13	0.270		
Commercial	0.16	0.24	0.25	1.20	0.246		
Transportation	0.11	0.00	0.08	2.69	0.307		
Open Space	76.74	59.66	76.45	82.98	0.587		
Unknown	21.71	39.25	21.27	0.00	0.395		

*after adjustment of Barton Zone: $p=0.05$, $r^2=0.89$, estimate=-0.39

Town Lake Flow

During the summer months from mid-March to mid-October when electrical demands rise and water demand is higher from agricultural operations located downstream of Austin on the Colorado River, the Lower Colorado River Authority (LCRA) releases more water through the Highland Lakes system and Town Lake flow is composed primarily of water from the Lake Travis hypolimnion. The residence time of Town Lake changes dramatically between these periods. Because of aquatic life impacts downstream of the Longhorn Dam impounding Town Lake and to maintain a minimum flow to the Matagorda Bay estuary during the non-release period, LCRA instituted a minimum 100 ft^3/s release policy beginning in 1992.

Previous Town Lake analyses (COA 2000) have defined these release and non-release periods based on calendar year (release = March 15 – October 14, non-release = October 15 – March 14). Based on Tom Miller Dam discharge values from LCRA (1976-2006), turbine-only ($p<0.0001$) and total release values ($p<0.0001$) are significantly different between traditionally defined seasons (Table 2.4). Turbine releases show a distinct monthly pattern with peak release in June and minimum release in November (Figure 2.6).

Table 2.4. Mean and median daily release values from Tom Miller Dam (1976-2006) by season.

ft^3/s	Release (03/15-10/14)			Non-Release (10/15-03/14)		
	Mean	Median	Std	Mean	Median	Std
Turbine-only	1408	1373	800	489	139	875
Turbine + floodgates	1751	1397	2289	1040	145	3578

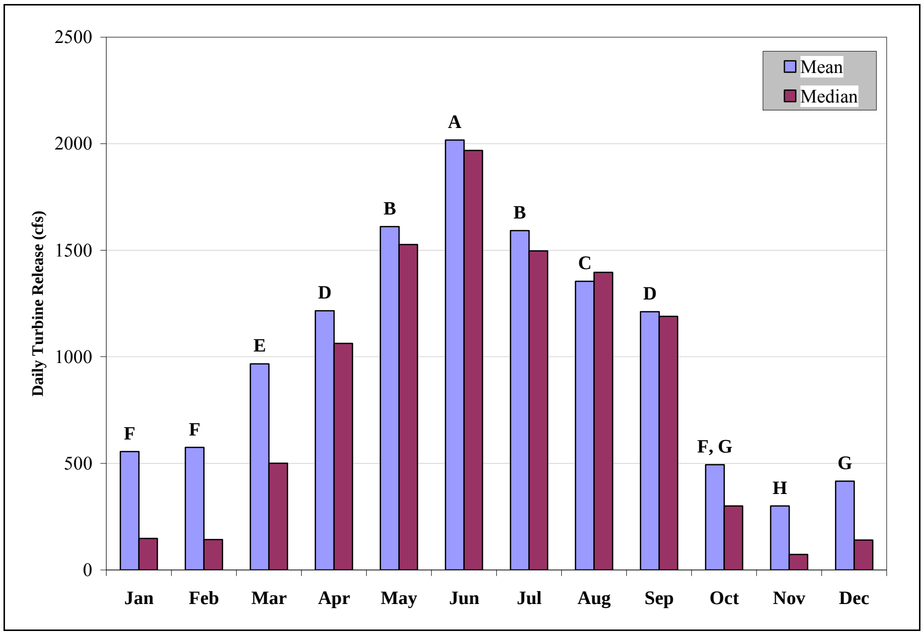


Figure 2.6. Tom Miller Dam mean and median daily turbine releases (1976-2006) by month with multiple range test results (REGWQ). Months with the same letter group are not significantly different ($p<0.05$).

Though total release and turbine-only release daily medians exhibit a similar pattern, average daily total release by month are more variable due to large floodgate releases in some months from large storm events (Figure 2.7). Comparison to average monthly rainfall totals shows a strong disparity in October/November rainfall and releases. October and November are critical months for algae blooms as flows are at a minimum while increased nutrients may be available from runoff events.

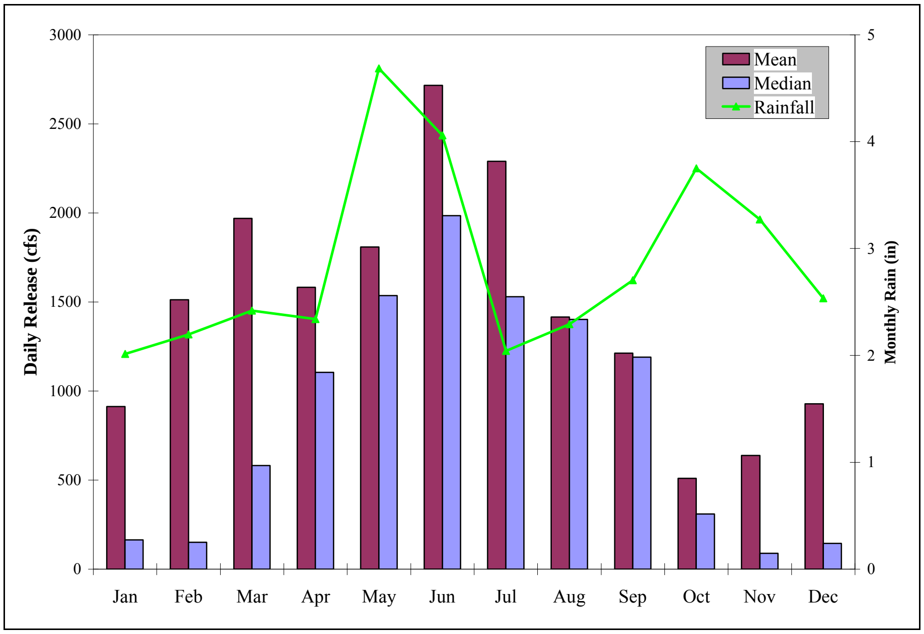


Figure 2.7. Tom Miller Dam mean and median daily total (turbine plus floodgate) releases (1976-2006) by month with average monthly rainfall totals (1976-2006).

Based on flow regime, Town Lake is most lacustrine from November to February and most riverine from April to September, with transitional periods in March and October. A visual review of the discharge records indicate that the traditional calendar groupings are generally accurate with a few exceptions. In several years the non-release period was very short in duration (Figure 2.8). Water quality data within the exception periods were classified as indicated by the review of flow data.

Data were grouped into water years based on the change in seasonal condition. There is no trend over time in number of days within each season by water year or calendar year (Figure 2.8). There is no trend over time in median discharge in the release season over the period of record. Although median discharge during the non-release season is increasing over time for the period of record ($p=0.0083$, $r^2=0.21$, estimate=5.3 $ft^3/s\bullet yr$), the trend is not significant when only data after the institution of the minimum flow policy in 1992 (Figure 2.9). This suggests that LCRA has generally not changed the release policy as it affects Town Lake.

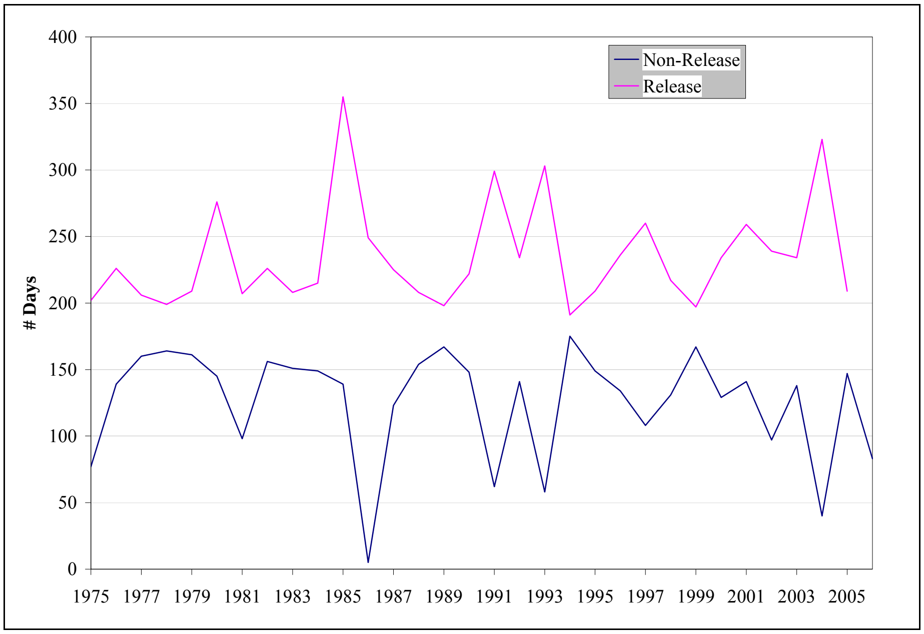


Figure 2.8. Number of days in the release and non-release periods by water year.

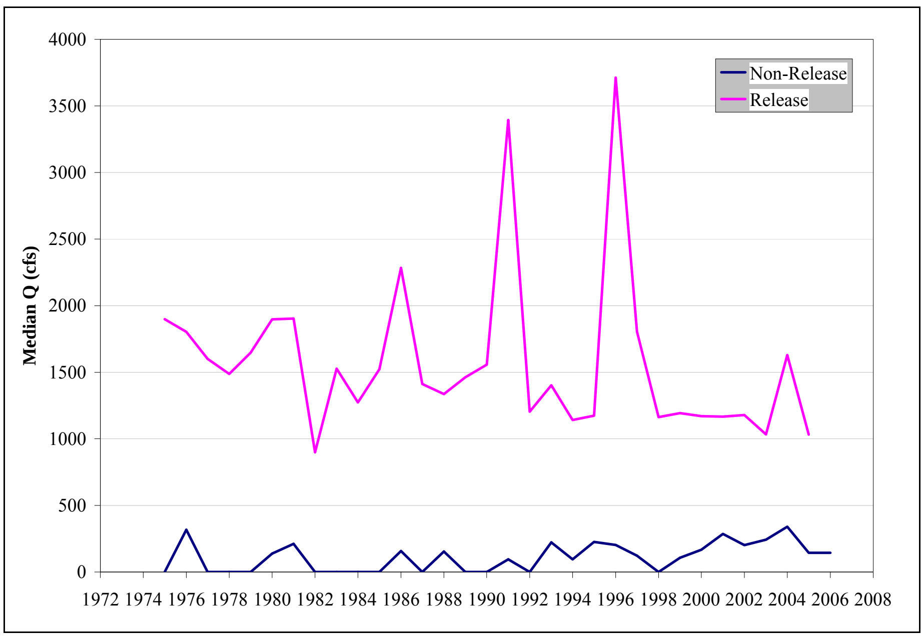


Figure 2.9. Median of total average daily discharge from Tom Miller Dam to Town Lake by water year.

Conclusions

Population with the Town Lake contributing areas downstream of Lake Travis continues to increase due to suburban expansion and urban infill. The highest annualized growth rate over the past three decades was experienced in the 1990s. The far western portions of the watershed (Barton Creek) could experience tremendous population growth in the future as a result of new water availability.

Both the number and size of building permits issued by the City of Austin in the Town Lake adjacent contributing watersheds are increasing over time.

Open space in the Lake Austin and upper Barton Creek zones and residential in the Town Lake zone dominate the land use of Town Lake in the Austin area. Residential and transportation land use in the Lake Austin zone are increasing over time at the expense of open space, although percent residential land use has actually decreased over time in the Town Lake zone. Large-scale future development and associated non-point source contaminant load is more likely to occur in the larger percentages of available open space in the Lake Austin and upper Barton Creek zones.

Data will continue to be grouped by season for analysis, though the start and end points of the release seasons will be adjusted by visually screening the flow record. There is no change over time in the number of days in each season or in the median discharge over time, accounting for the change in minimum flow policy instituted in 1992.

October and November could be critical months for algae blooms in Town Lake as flows are at a minimum and chances of runoff events are increased.

3.0 Water Quality

Currently, water quality samples are collected by boat at three locations on Town Lake (Basin, First Street, Red Bud) four times per year (twice in non-release, twice in release) during non-storm flow conditions by WRE staff (figure 3.1). USGS collect storm event samples twice per year at the same sites (once in non-release, once in release). Nutrients are collected at both surface and bottom depths, and field parameters are collected at 1 m interval depth profiles.

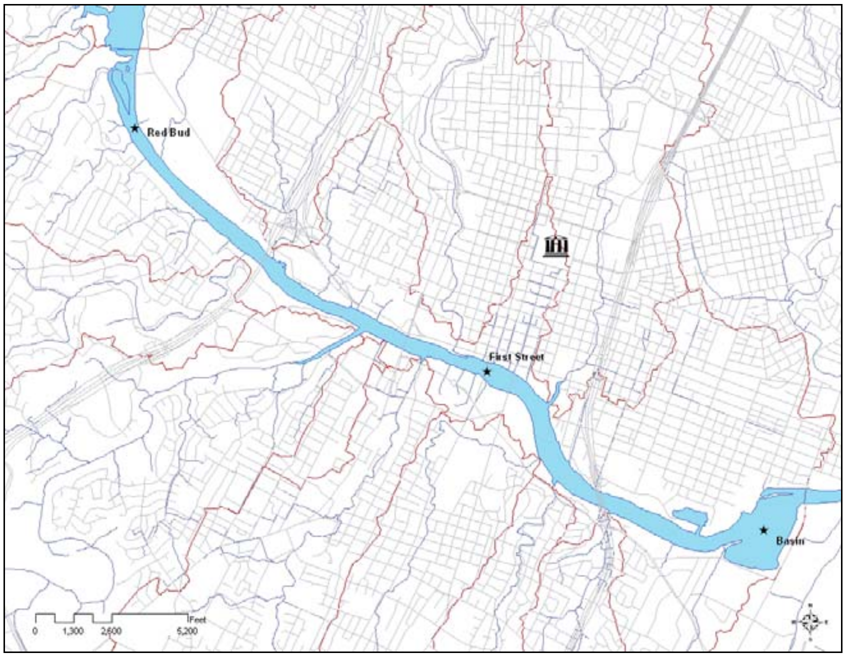


Figure 3.1. Map of current water quality monitoring locations.

Only water quality data collected by WRE and USGS were included in the analysis to provide for a balanced dataset with consistent collection methods. Data collected by Colorado River Watch volunteer monitors from 1996 to 2006 were not included as it was only collected from the shoreline. Austin Water Utility data, collected only at Red Bud from the shoreline, was not available after 2002 due to homeland security restrictions and was excluded. Data uploaded to the FSDB from the TCEQ database TRACS were excluded as that data is only available through 1999.

Parameters with no data collected after the previous Town Lake Report (COA 2000) or all data below detection limits were also excluded for this update. Only total suspended solids (TSS), volatile suspended solids (VSS), and bacteria samples collected at the surface were included for analysis.

Except for comparison to TCEQ standards, grab sample DO was analyzed using estimated DO percent of saturation calculated with associated sample temperature and assuming an elevation of 430 ft above sea level and a chlorinity of zero (APHA 1995). Total nitrogen was calculated for all samples that did not directly report total nitrogen for analysis as the sum of total Kjeldahl nitrogen (TKN) and nitrate.

Data analyses are generally performed on four data groups based on season (release/non-release) and flow type (storm/non-storm), or group differences were accounted for by analysis method.

TCEQ Standards and Screening Levels
The lower half of Town Lake is of concern on the TCEQ 2002 water quality inventory for nitrate/nitrite nutrient enrichment (TCEQ 2004). Town Lake surface samples were generally evaluated by TCEQ criteria (TCEQ 2003) to assess use support, though assessments were conducted annually. Nutrient samples were compared to TCEQ freshwater reservoir screening levels based on the 85th percentile of statewide data.

Over the past 10 years, Town Lake (at any individual site) has not been of concern (<25% exceeds) for ammonia, DO (surface measurements only), orthophosphorus, total phosphorus, pH, and water temperature. Town Lake chlorophyll-a concentrations have only been of concern (>25% exceeds) in 2000 and only at the First Street site. Town Lake nitrate/nitrite concentrations continue to exceed TCEQ screening levels at all sites (Figure 3.2), although the percent exceeds have decreased in recent years (no significant linear temporal trends). While elevated nitrate/nitrite from Barton Springs is clearly a source of the nitrate loading to Town Lake, the number of exceedances at Red Bud indicates an additional upstream component to elevated nitrate in Town Lake.

Comparing the average of all DO measurements for a given sample site and date to the TCEQ DO criteria indicates that in no year since 2000 have more than 25% of the samples exceeded the TCEQ limit at any site.

Bacteria during non-storm flow conditions are fully supporting contact recreation. Annual average chloride and sulfate concentrations have never exceeded the 75 mg/L standard in any individual year at any site, and estimated total dissolved solids (TDS, calculated as 0.65*conductivity) has not exceeded the 400 mg/L standard since 1991 at any site.

Arsenic, copper, mercury, and zinc (total or dissolved) in Town Lake have never exceeded TCEQ freshwater chronic criteria concentrations for the protection of aquatic life. Cadmium has exceeded the chronic criteria of 2 µg/L once in 1980 at Red Bud. Lead has never exceeded acute criteria, although a 2003 sample at the Basin exceeded the 8 µg/L chronic criteria.

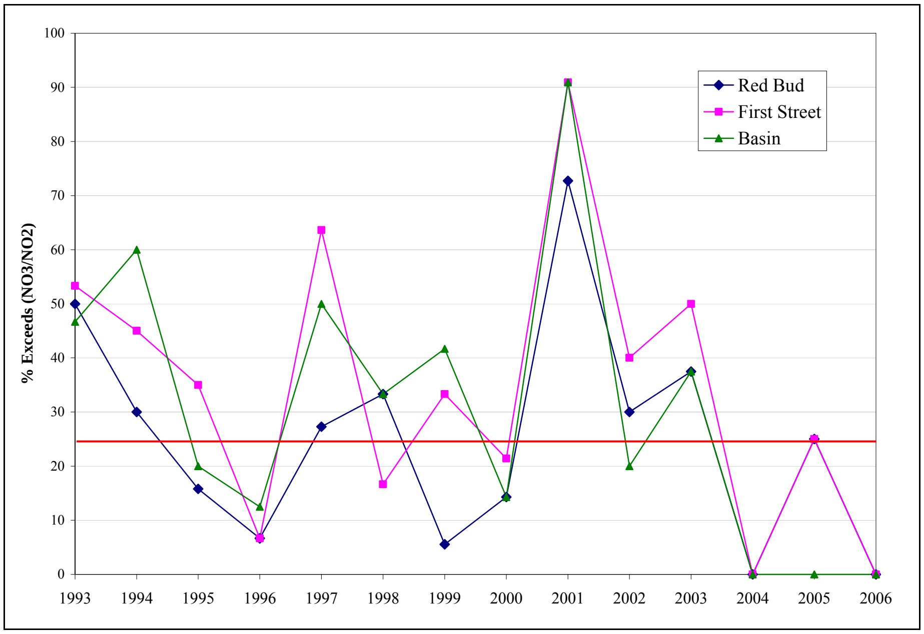


Figure 3.2. Town Lake percentage of nitrate/nitrite surface samples exceeding TCEQ screening level of 0.32 mg/L with 25% level of concern (red).

Patterns in Depth

Surface and bottom samples were compared by non-parametric Wilcoxon signed-rank test by parameter and season during non-storm flow conditions using data collected since January 2000 (Table 3.1). Based on historical analyses (COA 2000), the observed differences (or lack of differences) in DO, pH, temperature, ammonia, orthophosphorus, and phosphorus are expected.

Table 3.1. Results of signed-rank test for depth differences during non-storm conditions since 2000 ($\alpha \leq 0.05$).

Higher at:	Red Bud	First Street	Basin
DO (% saturation)	surface	surface	surface
pH	surface	surface	surface
Water temperature	surface	surface	surface
COD	no difference	no difference	no difference
Conductivity	bottom	no difference	bottom[1]
Chloride	no difference	no difference	no difference
Sulfate	bottom[2]	no difference	no difference
Ammonia (total)	no difference	no difference	bottom[2]
Nitrate/Nitrite (total)	bottom	no difference	bottom[2]
TKN	no difference	no difference	bottom[1]
Nitrogen (total)	no difference	no difference	bottom[1]
Orthophosphorus (total)	no difference	no difference	no difference
Phosphorus (total)	no difference	no difference	no difference

1. Significant in non-release season only
2. Significant in release season only

Nitrate/nitrite mean concentrations at Red Bud are substantially different at surface and bottom depths (Figure 3.3), and mean concentrations at depth at Red Bud have increased since the 2000 analysis. High nitrates at depth at Red Bud have been observed in year 2006 samples. Groundwater influences may be contributing to increasing nitrate/nitrite at Red Bud. Conductivity changes in some samples have suggested the existence of a groundwater upwelling near the Red Bud site. Colder Lake Austin inflows may also be contributing to Red Bud nitrate concentrations although historical analyses have previously indicated lower nitrate concentrations in Lake Austin. Barton Springs influences on the historical Lamar site, in which density changes from colder Barton Springs discharge affected nitrate concentrations at depth during summer release months, are not apparent at First Street.

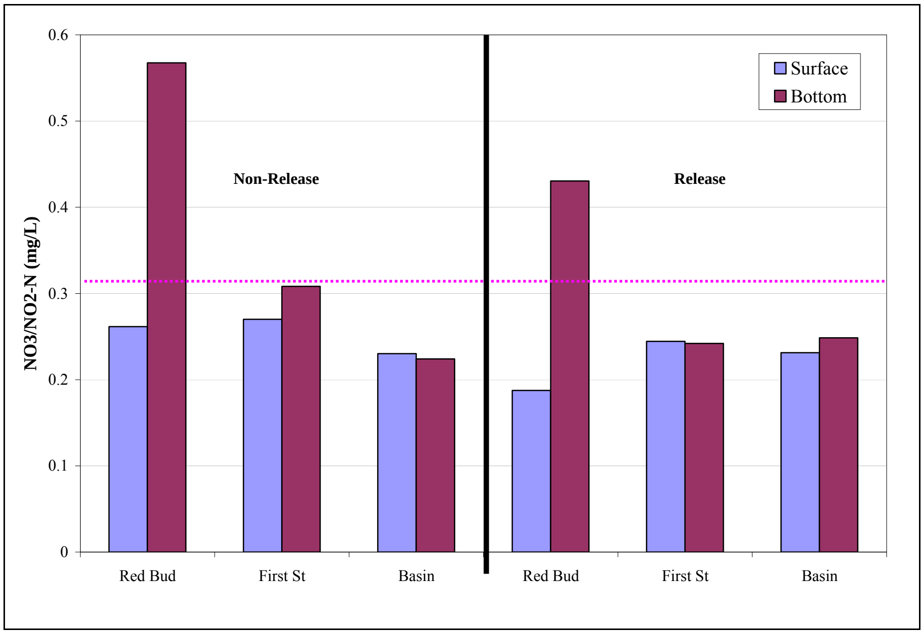


Figure 3.3. Nitrate/nitrite concentrations at surface and bottom depths by site during non-storm conditions with TCEQ screening level (0.32 mg/L).

Low DO values from instantaneous measurements continue to be problematic at the Basin (Figure 3.4), although DO values less than 3 mg/L have only been encountered on one sampling day in 1995 at First Street or Red Bud. The percentage of samples with DO values less than 5 mg/L (Pr>F=0.0469, r^2=0.13, estimate=0.69) and less than 3 mg/L (Pr>F=0.0336, r^2=0.14, estimate=0.63) are increasing over time by linear regression. Low DO values at the Basin are most likely to occur in the months of August to October when temperatures are elevated and/or flows decreased (Figure 3.5).

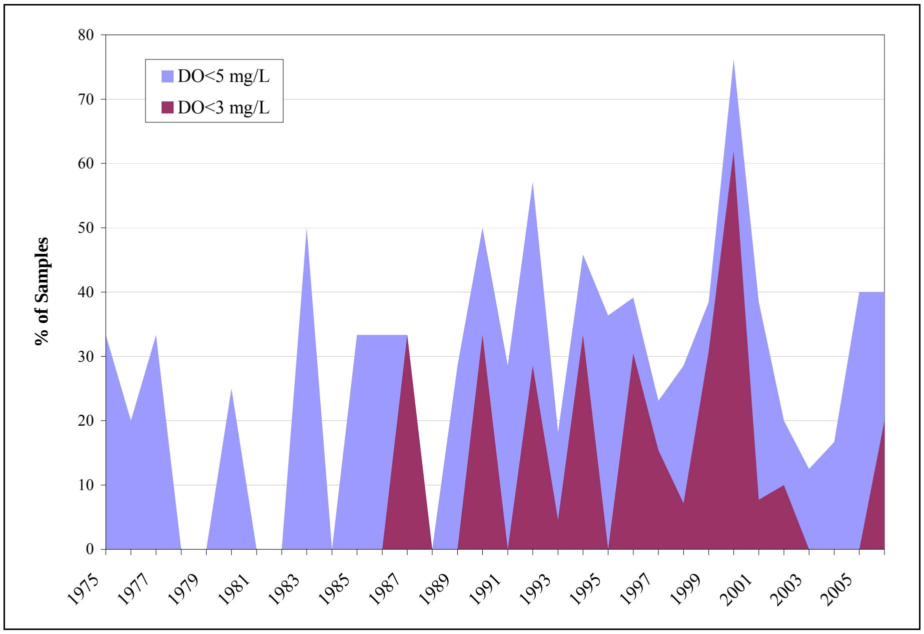


Figure 3.4. Percentage of sampling days with low DO values at the Basin by year.

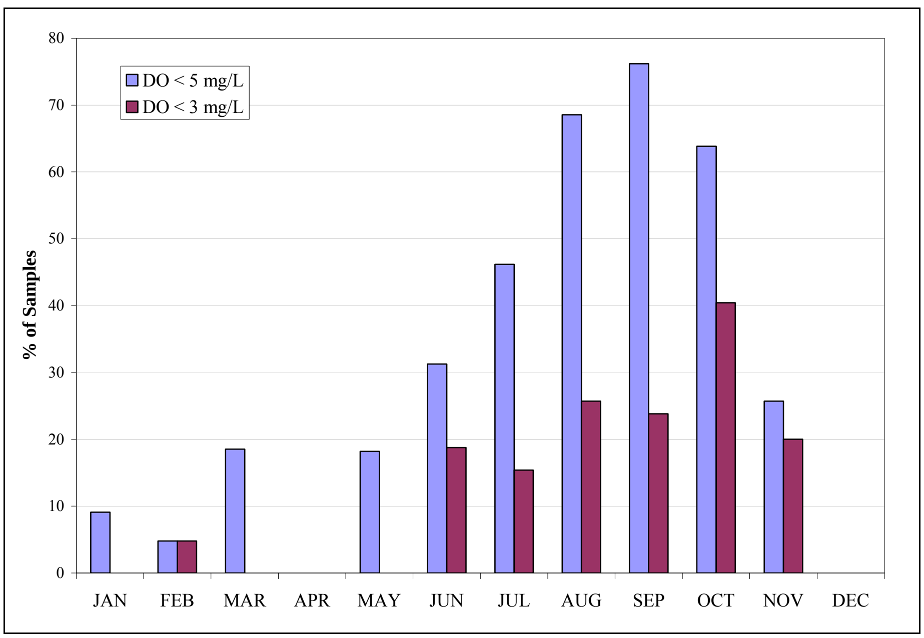


Figure 3.5. Percentage of sampling days with low DO values at the Basin by month.

Although the aerial extent of the problem cannot be determined from the single instantaneous sampling location at the Basin, the percentage of the water column experiencing low DO for a given sampling date can be evaluated (Figure 3.6). As more of the water column becomes anoxic, there is less refugia for mobile aquatic life to escape low DO conditions. Of course, sessile organisms cannot escape to the surface and would be subjected to the low DO conditions for the entire temporal extent of a low DO event. Over the period of record, the percentage of the Basin water column subjected to DO concentrations less than 5 mg/L (Pr>F=0.0171, r^2=0.02) and less than 3 mg/L (Pr>F=0.0037, r^2=0.03) is increasing over time by linear regression. Since year 2000, however, the percentage of the water column with DO less than 5 mg/L (Pr>F=0.0020, r^2=0.14) and less than 3 mg/L (Pr>F=0.0051, r^2=0.11) is decreasing over time by linear regression although as recently as August 2006 approximately 20% of the water column at the Basin was less than 3 mg/L.

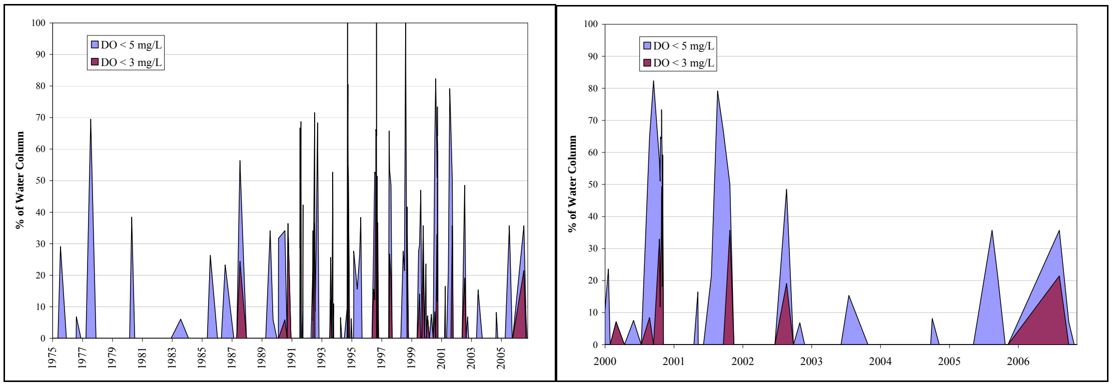


Figure 3.6. Percentage of water column with low DO by sample date at the Basin over the period of record (left) and since 2000 (right).

Monthly average DO (% saturation) profiles with depth in Town Lake at the Basin (Figure 3.7) indicate that the Basin is generally well mixed (not strongly stratified thermally) and operates as a more oligotrophic-like system during the months of December through May with approximately linear changes in DO with depth. From July to November (crossing the boundary of the traditionally defined release and non-release seasons), however, the Basin of Town Lake appears to operate as a more stratified, eutrophic-like system with sharp, nonlinear declines in DO with increasing depth. The most rapid decline in DO at the Basin occurs in September and October, consistent with previous analyses (COA 2000).

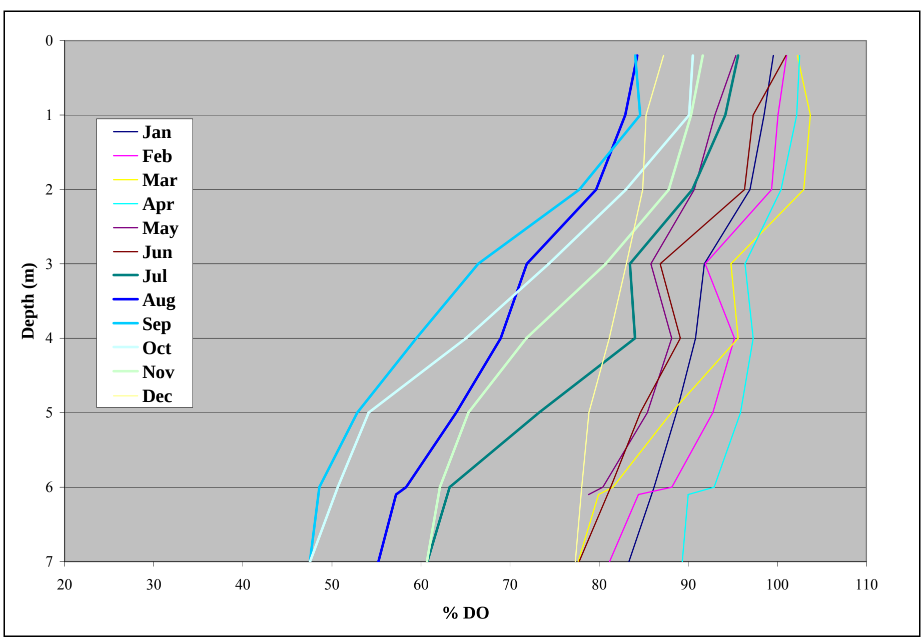


Figure 3.7. Mean DO (% saturation) with depth profiles by month at the Basin.

DO profiles with depth at the First Street and especially at Red Bud (Figure 3.8) are representative of a well mixed (not thermally stratified) and more oligotrophic system with DO concentrations linearly related to depth.

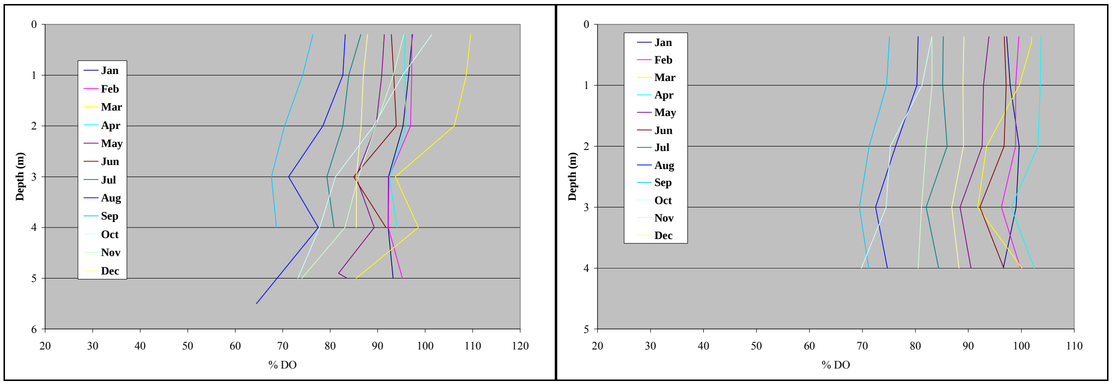


Figure 3.8. Mean DO (% saturation) with depth profiles by month at the First Street (left) and Red Bud sites (right).

Profiles of mean temperature at depth in the Basin (Figure 3.9) yield a maximum difference in surface and bottom temperatures in October (3.15ºC), with a minimum difference in temperature in January (1.68ºC) and little variation between other months (Table 3.2). Despite a larger total depth, the range in monthly surface and bottom temperatures differences are comparable between sites though the Basin does exhibit a more stratified temperature-depth profile than the other sites (Figure 3.10). However, the lack of a strong thermal stratification pattern at similar depths at the First and Red Bud sites and the relatively small variation in surface and bottom temperatures indicates at the Basin that observed patterns in DO at the Basin are more strongly influenced by algal growth dynamics and less influenced by temperature.

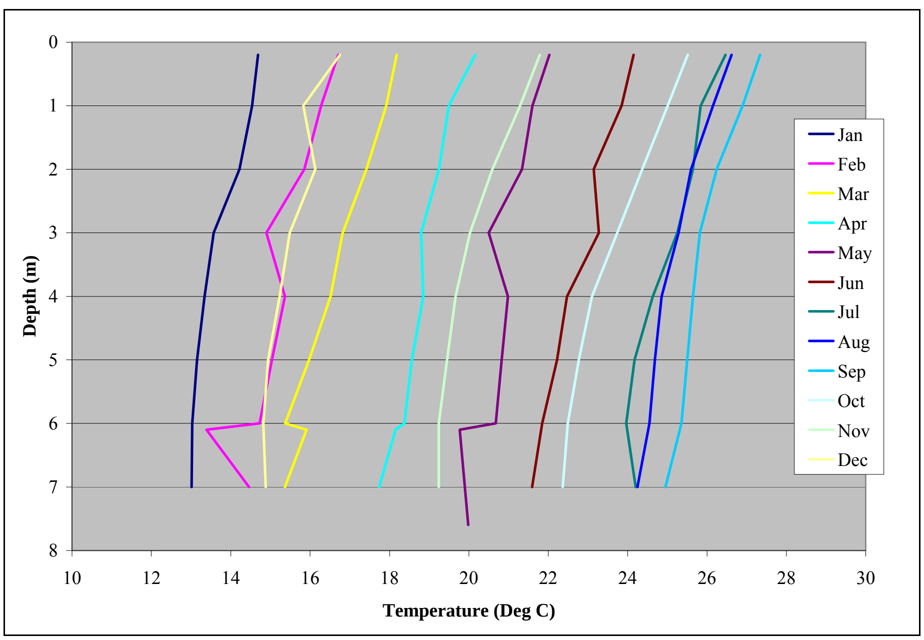


Figure 3.9. Mean temperature with depth profiles by month at Basin.

Table 3.2. Differences between mean surface and bottom temperatures (ºC) by month and site.

	Basin	First	Red Bud
January	1.68	1.27	1.63
Feb	2.25	0.54	1.13
Mar	2.82	1.69	1.23
Apr	2.42	1.39	0.30
May	2.04	0.82	0.48
Jun	2.55	1.05	0.66
Jul	2.26	1.42	0.46
Aug	2.37	2.08	1.87
Sep	2.38	0.98	1.99
Oct	3.15	1.02	1.10
Nov	2.55	0.97	0.94
Dec	1.87	0.83	0.98

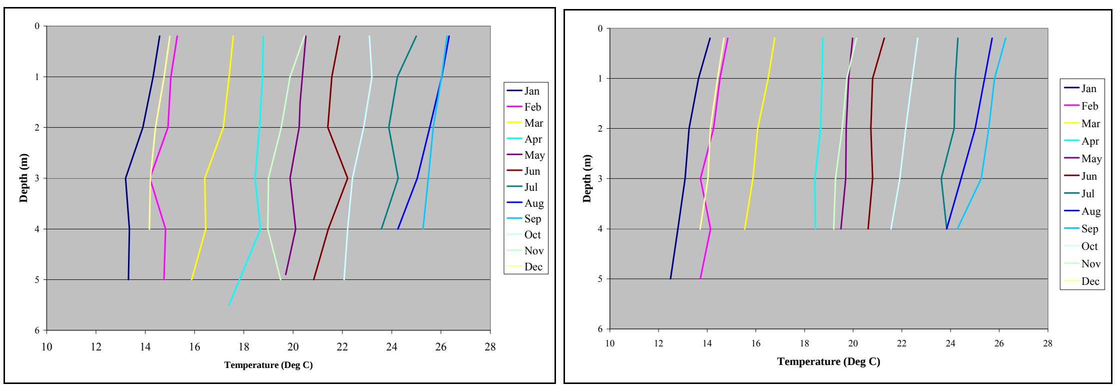


Figure 3.10. Mean temperature with depth profiles by month at the First Street (left) and Red Bud sites (right).

TCEQ (2003) guidance states that the mixed surface layer in a reservoir ranges from the surface to the depth at which the temperature decreases by 0.5ºC. Though not a direct measurement of the depth of thermal stratification, the percentage of the water column constituting the TCEQ-defined mixed surface layer was calculated for each site visit by season and by month (Figure 3.11). When aggregated by season, there is little difference between seasons at the Basin although the First Street and Red Bud are more likely to have shallower mixed surface layers during the non-release season. Monthly patterns indicate that the Basin is more likely to be less mixed (more likely to be stratified) than the upstream sites, particularly during August. If a composite sampling technique is to be used in the future, sampling must determine the mixed surface layer to be compliant with TCEQ procedures.

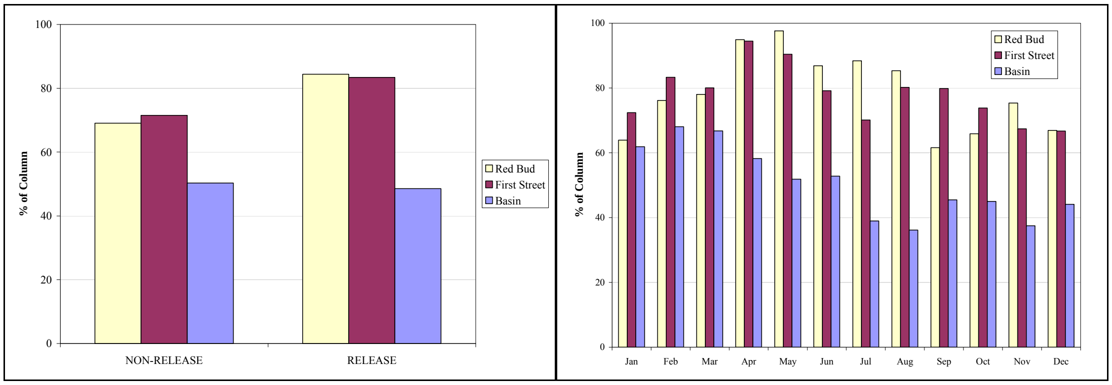


Figure 3.11. Mean percentage of the water column at each site constituting the mixed surface layer by season and by month.

Site Differences

Site differences were initially investigated by Cochran-Mantel-Haenszel (CMH) test based on rank scores controlling for sample date and depth (surface and bottom data only) using PROC FREQ in SAS. Controlling for date and depth eliminates the need to separate analyses based on season or specify depth effects. Analyses were separated by flow type, as the differences in relationships between sites under varying flow conditions is of interest.

The majority of parameters exhibit significant differences between sites by CMH test, indicating that Town Lake water quality continues to be spatially heterogeneous. In non-storm flow conditions, only COD, sulfate, pH, dissolved orthophosphorus, total orthophosphorus, and dissolved phosphorus were not different between sites by CMH. In storm flow conditions, only sulfate, conductivity were not different between sites by CMH.

Detailed site differences were investigated using Wilcoxon signed-rank test (with PROC UNIVARIATE) by parameter, flow type and depth with three separate two-way comparisons between Basin and First Street, First Street and Red Bud, and Red Bud and Basin (Table 3.3). Patterns in site mean differences can be generalized to three classifications: longitudinally increasing, longitudinally decreasing, and peaking at the First Street site (with varying differences between the Basin and Red Bud sites). Analyses were conducted on all data from the period of record as well as data separated into groups before and since January 2000 as an assessment of recent change in spatial patterns.

Table 3.3. Patterns in site differences from paired Wilcoxon signed-rank test.

Longitudinally increasing	**Longitudinally decreasing**	**Peak at First Street site**	**No difference between sites**
Ammonia	Conductivity (depth)	Bacteria (non-storm)	COD
Bacteria (storm)	DO (bottom)	Nitrate (surface)	Conductivity (surface)
Chlorophyll-a	Nitrate (bottom)	Total nitrogen (surface)	Chloride
DO (surface)	Secchi disk depth	TSS (storm)	Total nitrogen (depth)
Sulfate (surface)	Sulfate (depth)		Orthophosphorus
TKN			Phosphorus (surface)
TSS (non-storm)			
Temperature			
Phosphorus (depth)			
pH			

The effects of the Austin's urban downtown watersheds and Barton Creek on Town Lake are evident in the longitudinally increasing concentrations of ammonia, bacteria, chlorophyll-a, sulfate and TSS, and decreasing clarity represented by Secchi disk depth. Peaks in surface nitrate and total nitrogen at the First Street site are most likely due to elevated nitrate discharged from Barton Springs.

Patterns in orthophosphorus and total phosphorus site concentrations have changed over time to become not different between sites. Identification of the possible cause of the change in pattern is investigated by temporal trend analysis.

Due to longitudinally increasing temperature, DO would be expected to longitudinally decrease. However, the DO at surface depths actually increases from Red Bud to the Basin. The differences in DO patterns observed at surface and at depth are most likely a result of both the longitudinally increasing depth of Town Lake in combination with increasing biological oxygen demand and production from phytoplankton represented by chlorophyll-a (Figure 3.12). The lack of difference in phosphorus concentrations between sites in combination with the observed differences in nitrogen continue to suggest that Town Lake phytoplankton growth is phosphorus-limited.

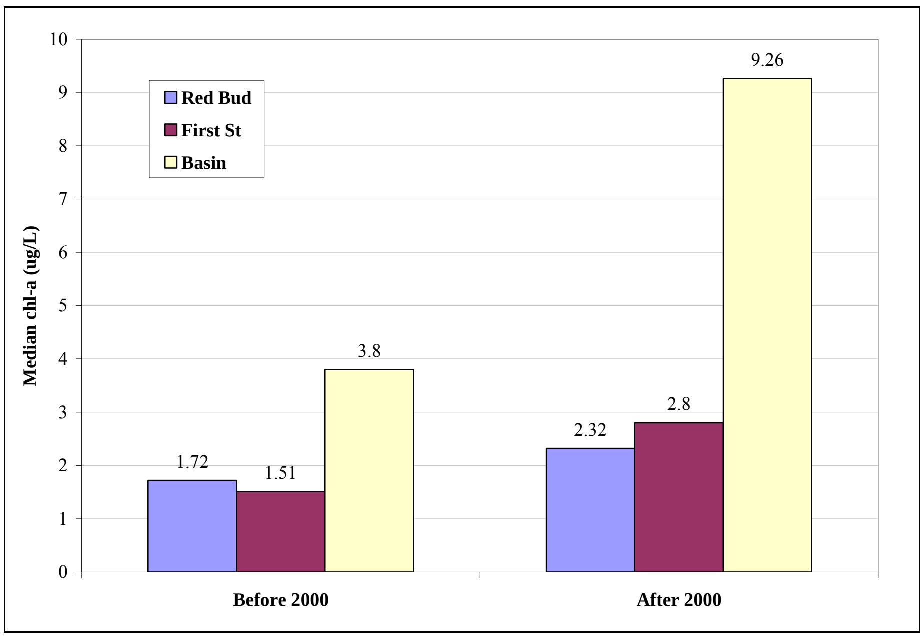


Figure 3.12. Median chlorophyll-a site concentrations before and after January 2000.

Seasonal Differences (correlation with flow)
Observed differences between seasons are most likely a function of relative upstream load contribution and variation in hydraulic residence time, though seasonal climatic effects (especially temperature) may also be a minor factor. Wilcoxon tests using all non-storm data grouped by depth indicate that chlorophyll-a, nutrients, conductivity, dissolved oxygen, and clarity (increased Secchi disk depth, reduced TSS) are generally higher in the non-release season. Metals show few seasonal differences (Table 3.4). Examination of only the data collected since January 2000, however, indicate that while chlorophyll-a, conductivity, TSS, metals, total nitrogen and total phosphorus are identical to results from the entire period of record, some nutrient species yield different results. Recent orthophosphorus concentrations are higher in release, and nitrate/nitrite concentrations are no longer different between seasons.

Although Lake Austin maintains higher baseline algae counts than Town Lake (see Section 7.0), upstream flows may have a dilution effect on Town Lake nutrients while negatively contributing to Town Lake clarity (most likely due to an increase in flow) during the release season.

Table 3.4. Summary of Wilcoxon test of season for all sites by depth during non-storm flow conditions.

PARAMETER	All data		Since 2000	
	Surface	Bottom	Surface	Bottom
CHLOROPHYLL-A	Non-Release	.	Non-Release	.
E COLI BACTERIA	No Diff	.	No Diff	.
FECAL COLIFORM BACTERIA	Release	.	No Diff	.
CHLORIDE	No Diff	No Diff	No Diff	No Diff
CONDUCTIVITY	Non-Release	Non-Release	Non-Release	Non-Release
SECCHI DISK DEPTH	Non-Release	.	No Diff	.
SULFATE	Non-Release	No Diff	Non-Release	Non-Release
TOTAL SUSPENDED SOLIDS	Release	.	Release	.
VOLATILE SUSPENDED SOLIDS	No Diff	.	No Diff	.
ARSENIC	No Diff	No Diff	No Diff	
CADMIUM	No Diff	No Diff		
COPPER	Non-Release	No Diff	No Diff	.
IRON	No Diff	No Diff	No Diff	.
LEAD	No Diff	No Diff	No Diff	
MERCURY	No Diff	No Diff		
ZINC	No Diff	No Diff	No Diff	.
AMMONIA AS N	Non-Release	Non-Release	No Diff	No Diff
NITRATE AS N	No Diff	No Diff		
NITRATE/NITRITE AS N	Non-Release	Non-Release	No Diff	No Diff
NITRITE AS N	No Diff	No Diff		
NITROGEN AS N	Non-Release	Non-Release	Non-Release	Non-Release
ORGANIC NITROGEN	No Diff	No Diff		
ORTHOPHOSPHORUS AS P	No Diff	No Diff	Release	No Diff
PHOSPHORUS AS P	Non-Release	No Diff	Non-Release	Non-Release
TOTAL KJELDAHL NITROGEN	Non-Release	Non-Release	Non-Release	Non-Release
CHEMICAL OXYGEN DEMAND	Non-Release	No Diff	Non-Release	Non-Release
DISSOLVED OXYGEN	Non-Release	No Diff	Non-Release	No Diff
PH	No Diff	No Diff	No Diff	Release
WATER TEMPERATURE	Release	Release	Release	Release

Temporal Trends

Multiple linear regression (COA 2000b) was used to model temporal trends for a smaller number of analysis groups, accounting automatically for differences in analysis lab, seasonality, filter fraction, and depth with a single regression equation. Categorical variables were represented by coded integer values, with the quantized variables in the regression equation entered first before other variables (Neter et al 1990, Helsel 2005). A backward elimination model removed parameters with regression coefficients yielding a significance value of less than 0.10 (SAS 2004). The general form of the full model (prior to backward elimination) is:

*result = lab lab*date filter filter*date season season*date depth depth*date date;*

If a term was not applicable (i.e., there was data from only one filter fraction), that term was not included in the full model. Trends were assessed using data from the entire period of record as well as data collected only since January 2000. Multiple linear regression results for parameters with censored observations (non-detect) were confirmed using the semi-parametric Cox proportional hazards regression (Allison 1995), with the quantized variables entered as separate strata. Plots of data were examined for all parameters to assess the validity of the analytically-determined trends. Following final model selection, a plot of residuals versus predicted values were examined for the absence of any marked trends to verify model fit and insure that no model assumptions were violated.

Table 3.5. Summary of temporal trend analysis.

Parameter	Recent (data since January 2000)	Period of Record
Ammonia as N	No trends	Decreasing at Basin (non-storm) and First (non-storm); Increasing at Basin (storm)
Arsenic	n/a	No trends
COD	No trends	Decreasing at Basin (storm) and Red Bud (storm)
Chloride	Decreasing at all sites	Decreasing at all sites
Chlorophyll-a	No trends	Increasing at all sites (non-storm)
Conductivity	Increasing at Basin; Decreasing at Red Bud	Decreasing at all sites
Copper	n/a	Decreasing at Basin (non-storm); Increasing at Basin (storm)
DO	Increasing at Basin; Decreasing at First (non-storm)	Decreasing at Basin and Red Bud (non-storm)
E coli	Decreasing at Red Bud (storm)	n/a
Fecal coliform	n/a	No trends
Iron	n/a	No trends
Lead	n/a	Decreasing at Basin
Nitrogen, Total	Decreasing at Basin and Red Bud	Decreasing at Basin and Red Bud (storm)
Nitrate/Nitrite	Increasing at Basin (storm)	Decreasing at Basin (non-storm); increasing at Red Bud (non-storm)
Orthophosphorus	Decreasing at all sites (non-storm)	Decreasing at all sites (non-storm)
pH	Increasing at Basin (non-storm) and Red Bud (storm); decreasing at First (storm)	Decreasing at all sites
Phosphorus, Total	Decreasing at all sites (non-storm)	Decreasing at Red Bud and Basin (storm)
Secchi disk depth	Increasing at First (non-storm); Decreasing at Red Bud (storm)	Increasing at Red Bud; Increasing at Basin (storm)
Sulfate	Decreasing at all sites	Decreasing at all sites
Temperature	Decreasing at First and Basin	Increasing at all sites
TKN	Decreasing at Basin (non-storm) and First (non-storm)	Decreasing at Basin (storm) and Red Bud (storm)
TSS	Increasing at Basin (non-storm) and Red Bud (storm)	Increasing at Basin (non-storm) and First (non-storm); Decreasing at Basin (storm)
Zinc	n/a	Decreasing at Basin

Over the period of record, ammonia is decreasing over time at the Basin and First Street although the trend is non-significant with data collected since January 2000. Total nitrogen, however, is significantly decreasing since 2000 at the Basin and Red Bud. Nitrate yields conflicting trends in non-storm flow over the period of record, decreasing at the Basin but increasing at Red Bud. Observed trends in nitrate are not significant since January 2000. Concentrations of metals (currently measured only at the Basin) are generally decreasing over the period of record.

Orthophosphorus is decreasing over time and phosphorus is decreasing over time using data collected since January 2000.

Conductivity, chloride, sulfate and pH are decreasing over time in Town Lake over the period of record. Recent data, however, yield increasing temporal trends in pH and conductivity at the Basin during non-storm flow conditions. Decreasing trends for sulfate and chloride continue in only data collected since January 2000. TSS may be increasing during non-storm flow over the period of record at Basin and First Street, but the trend is only significant at the 0.10 level and data since 2000 indicate a significant increase only at the Basin during non-storm conditions.

DO at the Basin may be improving over time in samples collected since January 2000 although analysis of the complete period of record yields a decreasing temporal trend at both the Basin and Red Bud. DO may be decreasing over time since January 2000 at First, although the trend is non-significant over the period of record. Temporal trends in temperature could explain the trends in DO at the Basin and Red Bud but not the recent decline in DO at First Street.

Although chlorophyll-a trends (particularly for post-2000 analysis) might be expected to decrease due to a change in sampling methodology to no longer intensively target algae blooms on an annual frequency, chlorophyll-a is increasing over time for the period of record.

Conclusions

Town Lake continues to be of concern for nitrate/nitrite according to TCEQ screening levels, including at the Red Bud site upstream of the confluence with elevated nitrate discharging from Barton Springs. Mean nitrate/nitrite concentration since January 2000 at depth at Red Bud are greater than the TCEQ screening level.

Low DO concentrations continue to be problematic at the Basin, particularly from August to October. Although the aerial extent cannot be evaluated, the percentage of the water column experiencing low DO conditions may be increasing over time. The Basin, also the deepest site, is less likely to be well-mixed vertically than the upstream sites, particularly in non-release months. Thermal stratification and DO profiles similar to those expected in eutrophic systems are observed at the Basin in the months from July to November.

Higher nutrient and chlorophyll-a concentrations and lower TSS are observed during the non-release period when Lake Austin inflows are at a minimum. Town Lake water quality continues to be spatially heterogeneous.

Discharges to Town Lake degrade the water quality of the Colorado River. The effects of the Austin's urban downtown watersheds and Barton Creek on Town Lake are evident in the longitudinally increasing concentrations of ammonia, bacteria, sulfate and TSS, and decreasing clarity (Secchi disk depth). Peaks in surface nitrate and total nitrogen at the First Street site are most likely due to elevated nitrate discharged from Barton Springs.

Comparison of site differences, DO-depth profiles and temperature-depth profiles indicate that DO dynamics in Town Lake are potentially more related to biological oxygen demand and production and less related to temperature. Lack of differences in phosphorus between sites in combination with observed differences in nitrogen confirm that Town Lake phytoplankton is most likely phosphorus-limited.

Changes in DO can be explained by changes in water temperature for the Basin and Red Bud, although the recent decline in DO at the First Street site appears to be independent of temperature change. Water quality may be improving over time in Town Lake for metals, dissolved solids, ammonia, TKN, total nitrogen, orthophosphorus and phosphorus.

Despite decreasing nutrients, chlorophyll-a over the period of record is increasing over time (although the trends are not significant for data collected since January 2000 suggesting that the system is relatively stable at present). Increasing clarity or increasing algal biomass loading from Lake Austin could drive the observed long-term increasing chlorophyll-a in Town Lake (and subsequent decreases in nutrient concentrations). If algal growth patterns continue to change, the impacts of algal biomass on Town Lake (particularly for DO) can be expected to change correspondingly.

Recommendations
Periodic investigation of the aerial and temporal extent of low DO values at the Basin over time during the months of August to October will determine the true scope and magnitude of potential aquatic life impairments from anoxic conditions. Potential trends in DO from grab sampling should be confirmed with diurnal DO measurements. Diurnal measurements could additionally be used to quantify the range of DO values as an assessment of the effect of algal growth on Town Lake DO.

Field staff should consider the definition of the mixed surface layer, especially at the Basin, for future sampling to insure TCEQ compliance when submitting data for the Clean Rivers Program.

If lab analysis costs become an issue, the number of sites sampled for COD can be reduced due to a lack of significant differences between sites. The number of sites sampled by the USGS during storm flow conditions could be reduced in favor of increasing frequency due to the general lack of site differences (or similarity to differences observed during non-storm flow conditions) during storm flow conditions. Analyses of storm flow data is complicated by the inconsistency of event sizes sampled and low sample frequency.

Source investigation, including a search for submerged spring outfalls and sampling of Lake Austin, of the elevated nitrate/nitrite throughout the lake should be considered if the elevated levels continue to be observed.

4.0 Sediment Quality

In addition to causing increased turbidity and potential filling of the river basin, sediments are an important storage compartment for many toxins released into surface waters. Because of their ability to sequester toxic compounds, sediments can reflect water quality and record the effects of anthropogenic emissions. As these toxins move through the water column and settle on the bottom, fish and other aquatic life may be exposed to them both through suspended sediments and in the benthic habitat. Fish accumulate toxins through water, plant and sediment pathways. Thus, their health and the use of the water body for fishing may also be negatively impacted by these toxins. Because of these impacts and observed toxins in fish tissue, the 1992 Town Lake Report (COA 1992) set a goal of reducing the toxin concentrations in sediment by 50%.

The Watershed Protection Master Plan (COA 2001) set goals in terms of maintaining the beneficial uses of the lake. A beneficial use affected by the toxins associated with the sediment is Aquatic Life Support (ALS), in terms of benthic and fish populations. To assess impacts to the benthic populations for this report, sediment concentrations are compared to two sets of sediment quality guidelines (SQGs) from an evaluation of guidelines for freshwater ecosystems (MacDonald et al 2000), and those used by TCEQ (TCEQ 2003).

The Watershed Protection Master Plan (COA 2001) also used a sub-goal to address the continued input rather than the level of toxins to the lake. The overall goal for toxic sediments, in assessing problem levels for the plan, was "to maintain existing toxic loads being discharged to Town Lake, represented by total organic carbon (TOC), chemical oxygen demand (COD), copper, lead and zinc loads, as well as by the Spills Risk Index." This goal will be assessed in future years to gauge the success of the Master Plan programs.

The objectives of sediment sampling in Town Lake are:

- **To insure the health of Town Lake for aquatic life and recreation:**
  Are Town Lake sediment concentrations above screening levels/standards?
- **To gauge success of master plan programs (goal of maintaining existing loads):**
  Are Town lake sediment concentrations changing over time? (Temporal Trends)
- **To compare Town Lake seasons for temporal differences:**
  Are mean values different between release and non-release seasons? (ANOVA)

Composite sediment samples are collected from the bottom of the Town Lake Basin (COA site #1) twice per year, once in the release and once in the non-release seasons. At least three sediment grab samples are collected during each sample event using a Ponar Dredge and composited. Sampling following scouring flood events is avoided. Current laboratory practical quantitation limits (PQL) are less than TCEQ probable effects levels (PEL) and 85th percentile screening levels for reservoirs for all parameters with available criteria (Table 4.1).

Table 4.1. Current sediment monitoring parameter list with lab detection limits (PQL) and TCEQ probable effects level (PEL) and 85th percentile screening levels for reservoirs (TCEQ 2003). All values in mg/Kg. Percent non-detects presented for the complete period of record

Lab	Lab PQL	Parameter	PEL	85th Perc.	TEC	PEC	% ND
Chlorophenoxy acid herbicides							
LCRA	0.0011	2_4_5-TP (SILVEX)		0.065			100
LCRA	0.0009	2_4_5-T		0.0345			75
LCRA	0.0008	2_4-D		0.33			75

LCRA	0.0015	DICAMBA					100
LCRA	0.0009	DINOSEB					100
LCRA	0.0009	PENTACHLOROPHENOL		3.85			100
Metals							
DHL	0.637	ARSENIC	17	32.7	9.79	33	6
DHL	0.127	CADMIUM	3.53	0.73	0.99	4.98	8
DHL	0.637	CHROMIUM	90	51.3	43.4	111	4
DHL	0.637	COPPER	197	26.8	31.6	149	2
DHL	159	IRON					0
DHL	0.127	LEAD	91.3	34.8	35.8	128	0
DHL	0.0391	MERCURY	0.486	0.168	0.18	1.06	26
DHL	0.637	NICKEL	35.9	33.5	22.7	48.6	0
DHL	0.127	SILVER		0.87			31
DHL	1.27	ZINC	315	143	121	459	0
Organochlorine pesticides							
DHL	0.00259	4_4'-DDD		0.0359	0.00488	0.028	45
DHL	0.00259	4_4'-DDE		0.0359	0.00316	0.0313	9
DHL	0.00259	4_4'-DDT	4.45	0.03475	0.00416	0.0629	40
DHL	0.00259	ALDRIN		0.03405			98
DHL	0.00259	ALPHA-BHC		0.03295			94
DHL	0.00259	ALPHA-CHLORDANE					100
DHL	0.00259	BETA-BHC		0.03405			100
DHL	0.00259	DELTA-BHC		0.03405			100
DHL	0.00259	DIELDRIN	0.00667	0.02668	0.0019	0.0618	67
DHL	0.00259	ENDOSULFAN I					100
DHL	0.00259	ENDOSULFAN II					100
DHL	0.00259	ENDOSULFAN SULFATE		0.03405			100
DHL	0.00259	ENDRIN	0.0624	0.03405	0.00222	0.207	100
DHL	0.00259	ENDRIN ALDEHYDE					100
DHL	0.00259	ENDRIN KETONE					100
DHL	0.00259	GAMMA-BHC (LINDANE)	0.00138	0.02345	0.00237	0.00499	100
DHL	0.00259	GAMMA-CHLORDANE					100
DHL	0.00259	HEPTACHLOR		0.02668			100
DHL	0.00259	HEPTACHLOR EPOXIDE	0.00274	0.0278	0.00247	0.016	92
DHL	0.00259	METHOXYCHLOR		0.059			100
DHL	0.00259	TOTAL CHLORDANE	0.0089	0.1725	0.00324	0.0176	27
DHL	0.0389	TOXAPHENE		0.695			100
Organophosphorus pesticides							
LCRA	0.0137	AZINPHOS METHYL		0.1725			100
LCRA	0.0143	DEMETON		0.203			100
LCRA	0.0143	DEMETON-O					100
LCRA	0.0097	DEMETON-S					100
LCRA	0.0126	DIAZINON		0.1605			81
LCRA	0.0112	PARATHION METHYL					100
PAH							
DHL	0.0099	ACENAPHTHENE		2.4			38
DHL	0.00495	ACENAPHTHYLENE		2.4			28
DHL	0.00495	ANTHRACENE		2.4	0.0572	0.845	28

DHL	0.0099	BENZO(A)ANTHRACENE	0.385	2.4	0.108	1.05	14
DHL	0.0148	BENZO(A)PYRENE	0.782	2.4	0.15	1.45	17
DHL	0.0099	BENZO(B)FLUORANTHENE		2.4			7
DHL	0.0148	BENZO(E)PYRENE					0
DHL	0.0099	BENZO(GHI)PERYLENE		2.4			14
DHL	0.0148	BENZO(K)FLUORANTHENE		2.4			21
DHL	0.0099	CHRYSENE	0.862	2.4	0.166	1.29	14
DHL	0.0099	DIBENZ(AH)ANTHRACENE		2.4			31
DHL	0.00495	FLUORANTHENE	2.355	2.4	0.423	2.23	13
DHL	0.00495	FLUORENE		2.4	0.0774	0.536	31
DHL	0.00495	INDENO(1_2_3-CD)PYRENE		2.4			14
DHL	0.00495	NAPHTHALENE		2.4	0.176	0.561	38
DHL	0.00495	PHENANTHRENE	0.515	2.4	0.204	1.17	21
DHL	0.0099	PYRENE	0.875	2.4	0.195	1.52	13
PCB							
DHL	0.0649	AROCLOR 1016		0.22			100
DHL	0.0649	AROCLOR 1221		0.34065			100
DHL	0.0649	AROCLOR 1232		0.22			100
DHL	0.0649	AROCLOR 1242		0.2474			100
DHL	0.0649	AROCLOR 1248		0.22			100
DHL	0.0649	AROCLOR 1254		0.22			92
DHL	0.0649	AROCLOR 1260		0.22			83
Supplementary Parameters							
LCRA		AMMONIA AS N	*no criteria*				
DHL		TOC	*no criteria*				
DHL		TPH	*no criteria*				
LCRA		Texture	*no criteria*				
DHL		Percent Moisture	*no criteria*				

For comparison to screening levels, temporal trends and ANOVA analyses, only parameters with data available after 2001 and at least one detected value since the period of record were included in this analysis. Sediment core samples collected by USGS were excluded.

Comparison to Screening Levels

Ambient sediment samples from Town Lake continue to yield contaminant levels potentially toxic to aquatic life (Table 4.2) above consensus-based probable effect concentrations (PEC). Polychlorinated biphenyls (PCB) and DDT pesticide degradates have been detected in Town Lake sediments as recently as 2006, with DDE concentrations detected above PEC levels. Polycyclic aromatic hydrocarbons (PAH) and mercury have also been detected above PEC levels within the last 3 years. Other metals (cadmium, lead, nickel) are consistently detected above potentially toxic consensus-based threshold effect concentration (TEC) values.

There are 81 parameters for which TCEQ screening levels exist that are not currently monitored by COA staff in Town Lake sediments. However, 78 of these parameters have been analyzed at least one time in Town Lake sediments previously and only 5 of the 81 have yielded values above detection limits (none detected above TCEQ screening levels).

Of the 3 remaining parameters which have not been analyzed in Town Lake sediments (2-chloroethyl vinyl ether; 1,2-diphenylhydrazine; hexachlorophene; diuron), two have been sampled at 92 other sites in Austin 148 times with no detected values to date. Only hexachlorophene, a broad spectrum prescription-only anti-bacterial formerly used in some hospital cleansers, has not been measured in Town Lake sediments although the substance has not been available over-the-counter since a withdrawal by the FDA in 1973.

Town Lake was not assessed for sediment contaminants concern on the 2004 TCEQ 303(d) list of impaired water bodies (TCEQ 2004). Comparison of Town Lake sediment data collected from 2002 to 2006 to TCEQ 85th percentiles by TCEQ assessment procedures (TCEQ 2003) indicate that at least the lower portion of Town Lake would be classified as only partially supporting general use due to the number of exceedances (# samples = 7) for lead, cadmium, copper, mercury and aroclor 1260.

Seasonal Differences

Of the 42 parameters with sufficient data for analysis, no parameters yielded a significant difference between seasonal release conditions by modified survival analysis Peto and Peto test (Prentice 1978) to account for the high proportion of non-detect measurements. Nine of the 41 parameters could not be compared because there were no detected measurements in one of the two release conditions.

Table 4.2. Summary of sediment data versus TCEQ 85th percentile screening levels for reservoirs (TCEQ 2003) and PEC/TEC concentrations (MacDonald et al 2000).

Parameter	% Samples Above Criteria	Last Detect Above Criteria	Comments
Above PEC/PEL			
Mercury	10.3	2003	12% above 85th percentile
Benzo(a)Anthracene	25.0	2005	66% above TEC
Benzo(a)Pyrene	8.3	2005	58% above TEC
Chrysene	16.7	2005	66% above TEC
Pyrene	15.4	2005	69% above TEC
Chlordane	57.6	2001	
4,4'-DDE	10.0	2006	86% above TEC
Above TEC, but not above PEC/PEL			
Lead	85.0	2005	Last detected above PEL in 1996
Cadmium	56.4	2004	Last detected above PEC in 1991
Nickel	15.4	2003	
Fluoranthene	53.8	2006	
Phenanthrene	16.7	2005	
Total PAHs	76.9	2006	No detects above PEC
Anthracene	8.3	2001	
4,4'-DDD	50.0	2006	Last detected above PEC in 1994
4,4'-DDT	50.0	2005	Last detected above PEC in 1994
Above TCEQ 85th Percentiles for Reservoirs			
Oil and Grease	100.0	2004	
Copper	31.4	2004	Last detected above TEC in 1996, no detects above PEC
Aroclor 1260	8.3	2006	
Other			
2,4,5-T	Detected above 85th percentile in 1981		
2,4-D			
Acenapthene			
Acenaphthylene			
Benzo(b)Fluoranthene			
Benzo(g,h,i)Perylene			
Benzo(k)Fluoranthene			
Dibenz(a,h)Anthracene			
Fluorene			
Indeno(1,2,3-cd)Pyrene			
Naphthalene			
Aldrin			
Alpha-BHC			
Aroclor 1254			
Arsenic	Detected above TEC in 1992		
Diazinon			
Dieldrin	Detected above TEC in 1981		
Heptachlor Epoxide	Detected above PEL in 1982; last detected in 1997		
PCB			
Chromium	Detected above PEC in 1987; last detect in 2006		
Silver	Detected above 85th percentile in 1990		
Zinc	Detected above PEL in 1998		

Temporal Trends
No chlorinated herbicide has been detected in Town Lake sediments at the Basin since 1981.

Fourteen of the currently monitored 22 organochlorine pesticides have never been detected in sediments at the Basin. Of the parameters with at least one detected value, only chlordane exhibits a significant temporal trend. Chlordane, banned for commercial use since 1988, is decreasing over time (Figure 4.1) by Cox proportional hazards regression ($n=33$, $p>\chi^2=0.0007$), and has not been detected since 2001. Concentrations of aldrin, α-BHC, dieldrin, or heptachlor epoxide have not been detected in Town Lake since 2000 or earlier. DDT and its degradates continue to be detected in Town Lake sediments although domestic DDT use was banned in 1972. Although there are no statistically significant trends over time for DDD, DDE, or DDT, mean concentration of DDT is significantly less ($P>\chi^2=0.0057$ by Peto and Peto test) after year 2000 compared to mean concentrations before 2000.

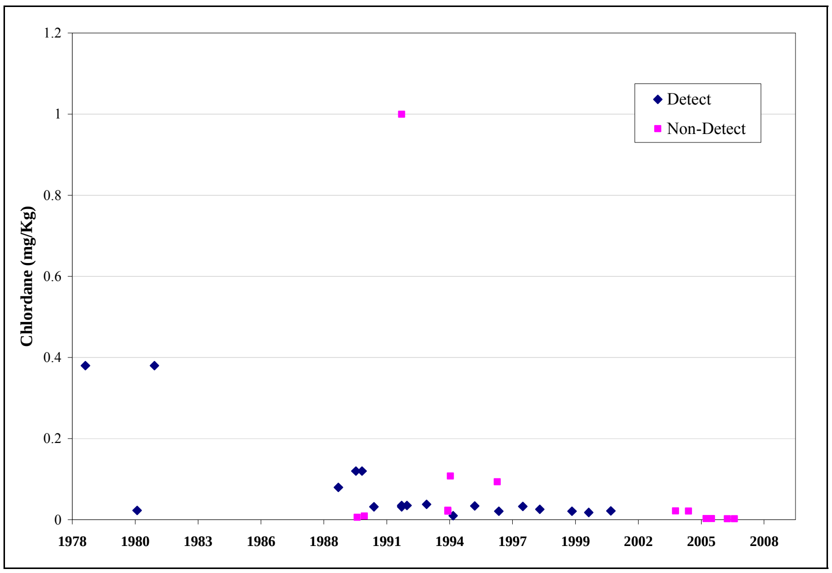


Figure 4.1. Total chlordane in sediment at the Basin over time.

Of the 6 organophosphorus pesticides currently monitored in Town Lake sediments, only diazinon has been detected and only in 1981.

Most aroclor (PCB congener) compounds are less than detection limits in Town Lake sediments for the period of record. Detected values have only been measured for aroclor 1254 and aroclor 1260, and values have been detected as recently as July 2006 (Figure 4.2). There is no significant temporal trend for any PCB congener or total PCBs.

Concentrations of the 17 individual PAH compounds currently monitored or calculated total PAH yield no significant temporal trends in Town Lake sediments over the period of record, though PAHs continue to be detected in recent samples.

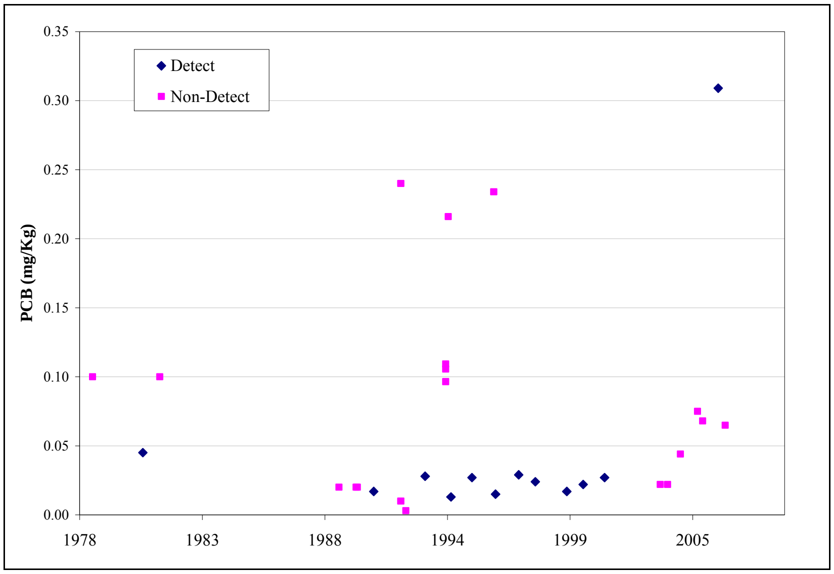


Figure 4.2. Total PCB in sediment at the Basin over time.

Concentrations of cadmium and lead are significantly decreasing over time (Table 4.3). Arsenic may be decreasing over time (Figure 4.3), though results between proportional hazards regression and linear regression on raw values are conflicting. Chromium, copper, mercury, and zinc were noted as decreasing over time in previous analyses (COA 2000), though now do not exhibit a significant temporal trend over the period of record. Removal of the single high zinc outlier (523 mg/Kg, May 1998) does not affect the (lack of) regression significance.

Only iron yields a significant increasing temporal trend. Increasing iron in sediment is most likely due to an increase in clay composition of sediments, either from a bias in sampling or change in character of sediments from contributing drainage. There is insufficient grain size data to normalize iron concentrations over the period of record. Iron concentrations increased dramatically around 1999, although the change cannot be explained by a change in analysis laboratory (almost all samples analyzed by the USGS until 2003).

Table 4.3. Summary of linear regression analysis for metals in sediment by Cox Proportional Hazards (PHREG) and general least-squares (GLM) methods.

Parameter	n	% non-detect	PHReg	GLM
ARSENIC	38	7.9	$p>\chi^2=0.44$	decreasing, $p=0.05$, $r^2=0.10$
CADMIUM	39	10.3	decreasing , $p>\chi^2=0.02$	decreasing, $p<0.01$, $r^2=0.24$
CHROMIUM	37	5.4	$p>\chi^2=0.28$	$p=0.17$
COPPER	35	2.9	$p>\chi^2=0.51$	$p=0.27$
IRON	25	0.0	n/a	increasing, $p<0.01$, $r^2=0.43$
LEAD	40	0.0	n/a	decreasing, $p<0.01$, $r^2=0.33$
MERCURY	39	25.6	$p>\chi^2=0.69$	n/a
NICKEL	13	0.0	n/a	$p=0.88$
SILVER	14	57.1	$p>\chi^2=0.08$	n/a
ZINC	37	0.0	n/a	$p=0.85$

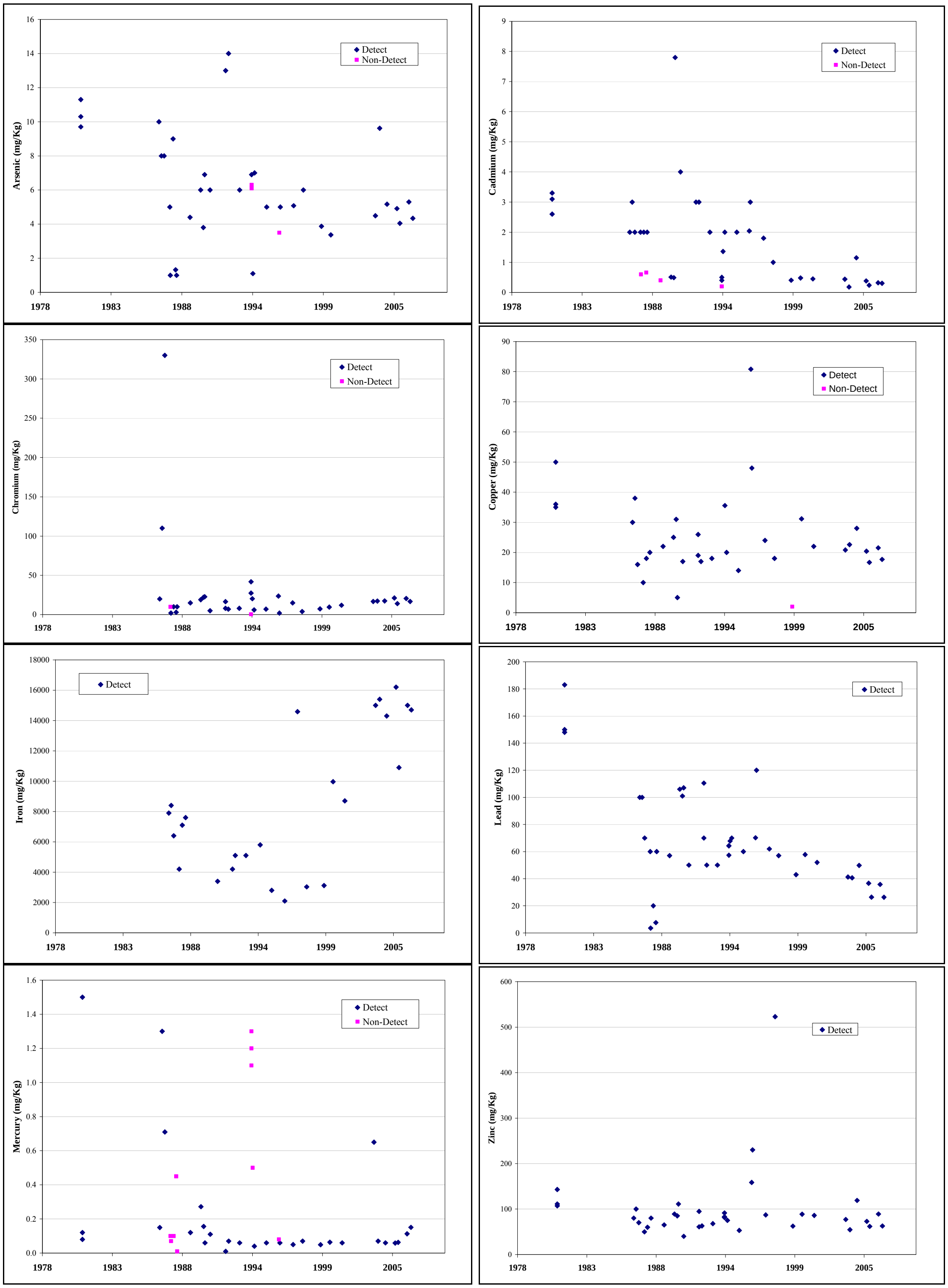


Figure 4.3. Metals in Town Lake sediment over time.

Source Identification

Anthropogenic or natural sources of metals in sets of sediment samples from a specific location can be distinguished by comparison to associated iron concentrations. Deviations from a linear relationship indicate an anthropogenic source for the metal (Mahler 2003). Relation of metals to iron in Barton Springs suspended sediments indicated anthropogenic sources for lead and zinc, but natural sources for arsenic, chromium, copper and nickel in Barton Springs suspended sediments (Mahler 2003).

Relation of metals in Town Lake sediment to associated iron concentrations and comparison to observed Barton Springs ratios indicate anthropogenic sources for lead and potentially for cadmium and zinc. Natural sources are generally indicated for arsenic, chromium, copper, nickel and mercury (Figure 4.4). Sediments collected by grab sampling in Barton Springs, not large volume suspended sediment sampling, were used for consistency with Town Lake sediment sampling methods. Although the majority of mercury samples indicate a natural source, three samples (from 1987, 1991 and 2003) strongly deviated from the natural source ratio and may indicate an intermittent anthropogenic source of mercury to Town Lake. Several arsenic, cadmium, chromium, and zinc samples also deviate from the observed natural background ratio and may also have some intermittent anthropogenic source component.

As demonstrated with temporal trend analysis, Town Lake sediment concentrations may be changing over time for some constituents. Ratios of metals to iron concentrations would logically be expected to change over time if sources were changing over time. Iron concentration is increasing in Town Lake sediments over time by linear regression ($n=25$, $p=0.0026$, $r^2=0.43$). No increasing temporal trends are observed in metals concentrations.

Decreasing metal-iron ratios over time coupled with decreasing (or no) temporal trends in metals concentration and increasing temporal trends in iron concentration indicate a potential change in source over time (i.e., a reduction in anthropogenic source). This pattern is observed for arsenic, cadmium, chromium, lead, mercury and nickel. No change in concentration over time or the ratio to iron over time is observed for copper or zinc. The lack of an increase in metal to iron ratios and increase in metals concentrations over time indicates no increase in anthropogenic sources of metals to Town Lake sediments.

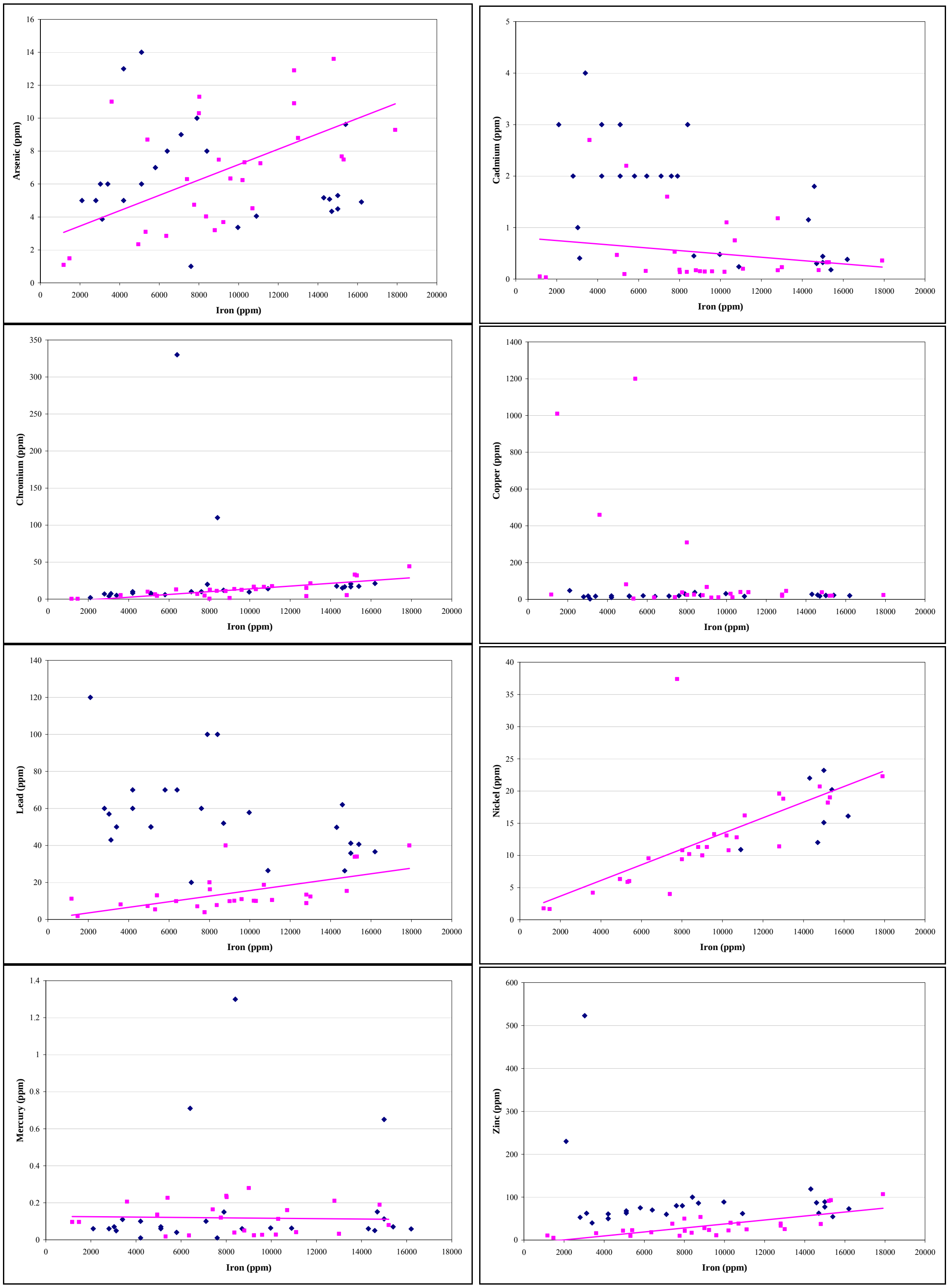


Figure 4.4. Metals versus iron in Town Lake sediment (blue) and Barton Springs sediment (pink) with linear regression line for Barton Springs sediments.

Comparison to Large Events

Concentrations of metals were compared by Spearman correlation analysis to number of days since large storm events as a simple test of the effect of large storm events on Town Lake sediment contaminants. Daily average discharge from the USGS gage on the Colorado River at US183 was used as a surrogate for Town Lake flow. Metals were selected due to the high percentage of consistently detected values for most parameters. No significant correlation coefficients were found for any of the 10 currently monitored metals versus days since events larger than 5,000 ft^3/s (~95th percentile) or 20,000 ft^3/s (~99th percentile).

As a secondary check, the correlation was repeated for both large event sizes but partial with the days from the last event to the second to the last event. Again, there were no significant correlations between metals and days since event for either event sizes for any metal. Sediment contaminants do not appear to be simply related to large storm events.

Comparison to Creek Sediments

Town Lake sediments were compared to contributing Austin creek sediments collected for the Environmental Integrity Index by non-parametric Wilcoxon rank sum test or modified Peto and Peto test for datasets with censored values. Only comparable periods of record were used. Although Town Lake sediments are generally higher in metals, creek sediments have higher concentrations of PAHs and PCB, including PCB congener aroclor 1260 (Table 4.4). Concentrations of iron are not different between Town Lake and creek sediments.

Due to the observed temporal trends in metals concentrations, Wilcoxon matched pairs test was used to additionally compare Town Lake and contributing creek sediments from the most similar sampling dates. Mercury and silver were excluded due to the high proportion of censored data. The time between associated lake and creek sampling events was highly variable. In this reduced dataset, Town Lake sediments continue to yield higher concentrations of cadmium, copper, lead and zinc than matched creek sediments with no significant different for other metals tested.

Table 4.4. Comparison testing of Town Lake and contributing creek sediments by Wilcoxon rank sum and modified Peto and Peto test over comparable period of record.

Parameter	Creek Data				Wilcox	Peto	Mean (mg/Kg)		Higher in?
	# samples	# censored	First	Last	Pr > |z|	Pr >x2	Creeks	Town Lake	
Metals									
Arsenic	35	3	1996	2006	0.0291	0.0253	5.56	6.33	Town Lake
Cadmium	39	1	1995	2006	0.0137	0.0057	0.56	0.74	Town Lake
Chromium	17	0	2003	2006	0.1123	0.0981	283.91	282.29	.
Copper	41	0	1994	2006	0.0001	0.0001	11.25	29.93	Town Lake
Lead	41	0	1994	2006	0.0001	0.0001	35.89	74.37	Town Lake
Mercury	41	25	1994	2006	N/A	0.0001	0.03	0.11	Town Lake
Nickel	26	0	2000	2006	0.3905	0.3856	21.04	17.08	.
Silver	26	20	2000	2006	N/A	0.0001	0.07	0.17	Town Lake
Zinc	41	0	1994	2006	0.0001	0.0001	56.34	111.17	Town Lake
Iron	9	0	2004	2006	0.0875	0.0651	13374.40	14416.70	.
PAHs									
Acenapthene	41	37	1994	2006	N/A	0.0075	0.040	0.008	Creeks
Acenaphthylene	41	36	1994	2006	N/A	0.1082	0.012	0.016	.
Anthracene	41	31	1994	2006	N/A	0.0734	0.121	0.042	.
Benzo(a)anthracene	41	11	1994	2006	N/A	0.0005	1.387	0.306	Creeks
Benzo(b)fluoranthene	40	8	1994	2006	N/A	0.0004	2.413	0.615	Creeks
Benzo(k)fluoranthene	40	14	1994	2006	N/A	0.0367	1.159	0.393	Creeks
Benzo(ghi)perylene	41	16	1994	2006	N/A	0.0095	1.319	0.330	Creeks
Benzo(a)pyrene	41	9	1994	2006	N/A	0.0003	1.455	0.415	Creeks
Chrysene	41	10	1994	2006	N/A	0.0011	1.977	0.483	Creeks
Dibenz(a,h)anthracene	41	29	1994	2006	N/A	0.2212	0.381	0.071	.
Fluoranthene	41	8	1994	2006	N/A	0.0022	2.938	0.706	Creeks
Fluorene	41	36	1994	2006	N/A	0.3193	0.032	0.013	.
Indeno(123-cd)pyrene	41	15	1994	2006	N/A	0.0367	1.332	0.403	Creeks
Naphthalene	41	38	1994	2006	N/A	0.7585	0.008	0.006	.
Phenanthrene	41	11	1994	2006	N/A	0.0002	1.000	0.162	Creeks
Pyrene	41	9	1994	2006	N/A	0.0004	3.141	0.636	Creeks
Pesticides									
Aldrin*	40	38	1994	2006	N/A	N/A			.
Chlordane	22	17	1994	2006	N/A	0.7731	0.062	0.023	.
Dieldrin	40	34	1994	2006	N/A	0.2467	0.008	0.001	.
Diazinon	9	9	1994	2006	N/A	N/A			.
2_4-D	7	7	2000	2006	N/A	N/A			.
2_4_5-T	7	7	2000	2006	N/A	N/A			.
Heptachlor epoxide	40	37	1994	2006	N/A	0.0483	0.005	0.001	Creeks
4_4'-DDD	40	29	1994	2006	N/A	0.1796	0.031	0.015	.
4_4'-DDE	40	21	1994	2006	N/A	0.0162	0.022	0.051	Town Lake
4_4'-DDT	40	23	1994	2006	N/A	0.8896	0.015	0.034	.
PCB									
PCB	32	30	1994	2004	N/A	0.0004	0.158	0.037	Creeks
Alpha-BHC	40	40	1994	2006	N/A	N/A			.
Aroclor 1254	27	27	1995	2006	N/A	N/A			.
Aroclor 1260	27	26	1995	2006	N/A	0.0529	0.170	0.050	Creeks

Conclusions

Ambient sediment samples from Town Lake continue to yield contaminant levels potentially toxic to aquatic life for PCB, DDE, metals and PAHs. Current analytical methods are generally sufficient to compare Town Lake sediments to applicable screening levels.

There appear to be no seasonal differences in sediment quality in Town Lake. Concentration of metals in sediment do not appear to be correlated to number of days since large storm events.

Cadmium and lead are decreasing over time in Town Lake sediments. Lead in Town Lake sediments is probably from anthropogenic sources. Anthropogenic sources may also contribute to arsenic, cadmium, chromium, mercury, and zinc in Town Lake sediments. Anthropogenic sources of metals to Town Lake may be decreasing over time. Iron is increasing over time, potentially from a change in the percent clay of Town Lake sediments, though there is insufficient grain size data for comparison.

Despite an observed reduction in metals, there are no significant temporal trends in PAHs or PCBs. Chlorinated herbicides and organophosphorus pesticides have not been detected in Town Lake sediments since 1981. Concentrations of some organochlorine pesticides in sediments, including chlordane and DDT, may be decreasing over time.

Although Town Lake sediments are generally higher in metals, creek sediments have higher concentrations of PAH and PCB.

Recommendations

A one-time sample for hexachlorophene in sediment should be performed in Town Lake and compared to TCEQ screening levels.

Based on frequency of detection in the complete period of record for currently monitored parameters, only 2 of the 6 chlorophenoxy acid herbicides (2,4,5-T and 2,4-D) and only 1 of the 6 organophosphorus pesticides (diazinon) have been detected. If future contract laboratories costs can be reduced by specifically targeting these individual parameters, additional parameters could be added or sample frequency could be increased with no additional expense.

Based on the lack of recent detected values, discontinue or reduce frequency of monitoring for chlorinated herbicides and organophosphorus pesticides in sediment at the Basin, or consider monitoring at a different locations in Town Lake.

Continue analysis of texture parameters to assess future changes in iron concentrations.

Consider appropriate method for coordinating future creek and lake sediment sampling events if further comparisons of Town Lake and contributing creek sediments are to be made.

5.0 Visual Index of Pollution

Trash and debris in Town Lake have been indicated as a problem historically (COA 1992). The removal of trash has been a goal for the lake since 1992, and the goal to reduce visual pollution and enhance the recreational activities of the lake remains in the Watershed Protection Master Plan (COA 2001). The visual index of pollution (VIP) is currently used as part of the Watershed Engineering and Field Operations Division (WEFOD) of WPDRD performance measure for trash and debris abatement.

The objectives of the VIP are:

- Provide a visual assessment of trash on Town Lake that can be quantified for use in prioritizing clean-up efforts.
- Assess the attainment of the WPDRD goal of maintaining an annual lake-wide average VIP score ≤ 2.
- Provide new information related to the nature and location of trash/debris and some measure of litter that can be used to target public education efforts.

The VIP began in April 1994. A photometric index was used from 1994 to 1999. Results from the photometric assessments are available in the Town Lake Report (COA 2004). Since 1999, staff have conducted quarterly on-site surveys from a boat, assessing 42 contiguous sites along the shoreline (Figure 5.1). Two or more staff members independently estimate the VIP with scoring categories ranging from 1 (0-25% litter cover) to 4 (75-100% litter cover), based on the Keep America Beautiful Litter Index descriptors and percent cover measurements as modified from the Daubenmire cover classes (BLM 1996). Results from each survey are averaged by site.

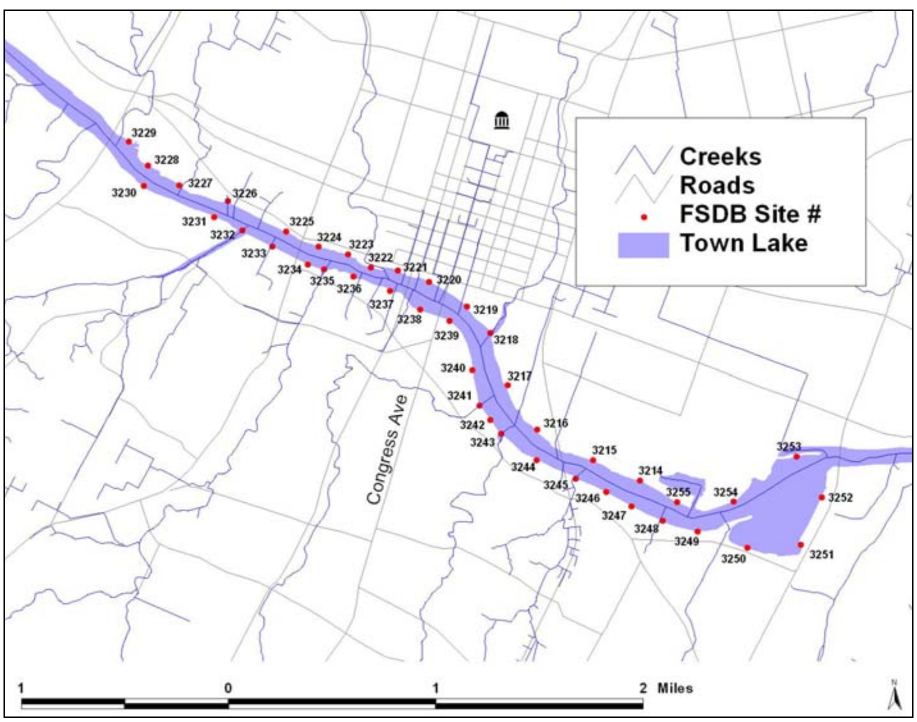


Figure 5.1. Town Lake VIP sites

Only data collected under current protocols since 1999 was included in analysis. One incomplete survey (02/07/1999) was excluded as the survey was repeated completely on 02/29/1999. Site #3222 (Town Lake VIP Site 9) at the mouth of Shoal Creek was not monitored during every survey unless the mouth of Shoal Creek was visible from the boat. All other sites have generally been monitored 30 times from 1999 to 2006.

For all sites averaged, no quarterly or annual survey has yielded a mean lake-wide VIP greater than 2. However, 7 of 42 sites, all located along the southern shore near IH-35, yield a long-term mean VIP greater than 2 (Figure 5.2). Most of these sites are downstream of the confluence with Waller Creek , a major urban tributary that typically brings in large amounts of floatable debris during storm events. Currents and wind often carry the debris across the lake to the opposite shore. The percentage of surveys with a VIP greater than or equal to 2 by site yield a similar pattern to average mean VIP scores.

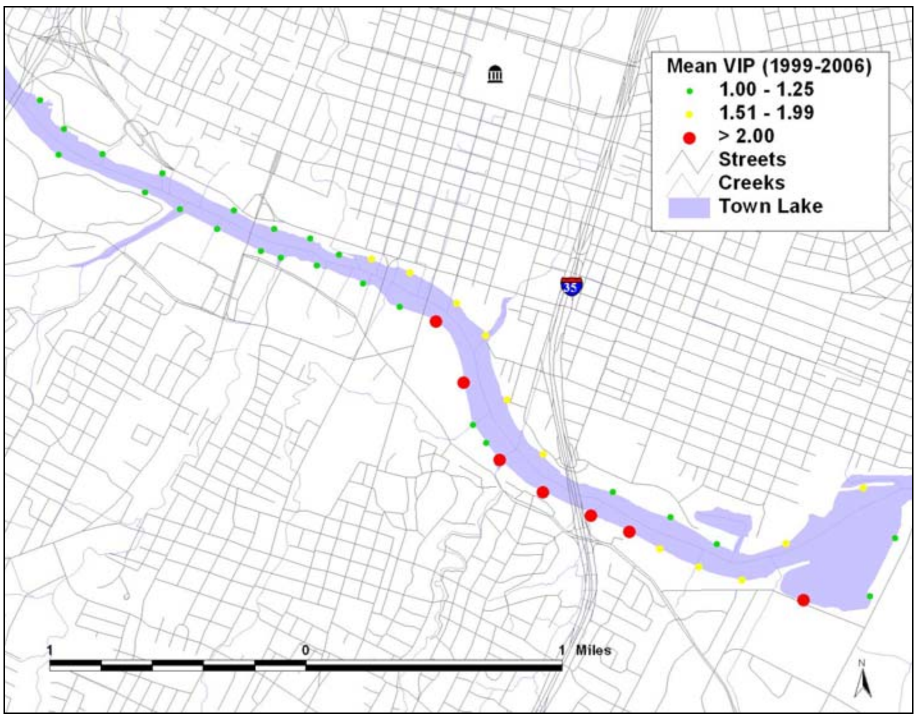


Figure 5.2. Town Lake VIP site means (1999-2006).

Both quarterly (n=30, p=0.0022, r^2=0.2897) and annual (n=8, p=0.0049, r^2=0.7587) lake-wide average VIP scores are decreasing over time from 1999 to 2006 by linear univariate regression (Figure 5.3). Significant decreasing linear temporal trends in VIP scores were observed at 12 of 42 sites based on data from 1999 to 2006 (remaining sites exhibited no significant trends). There is no clear pattern to the spatial distribution of sites exhibiting decreasing temporal trends in VIP score (Figure 5.4). Four of the 7 sites with mean VIP scores greater than 2, however, yield significant decreasing temporal trends in VIP score. Based on performance measure tracking by WEFOD, the tons of litter and debris removed per fiscal year 1996 has increased over time (Figure 5.5), potentially contributing to improving VIP scores, though the trend is non-significant (p=0.1857).

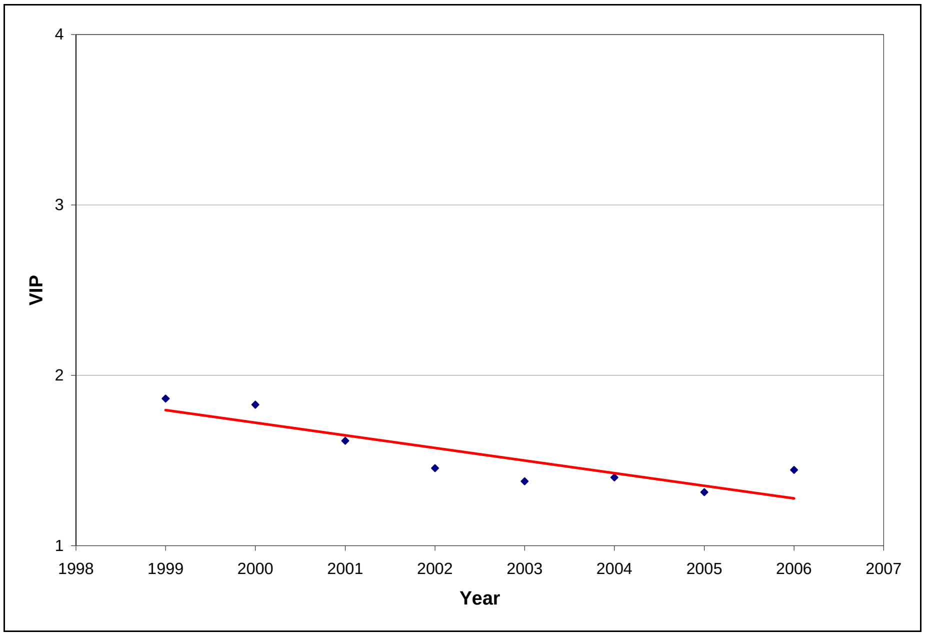


Figure 5.3. Annual average VIP scores over time with linear regression ($p=0.0049$, $r^2=0.7587$)

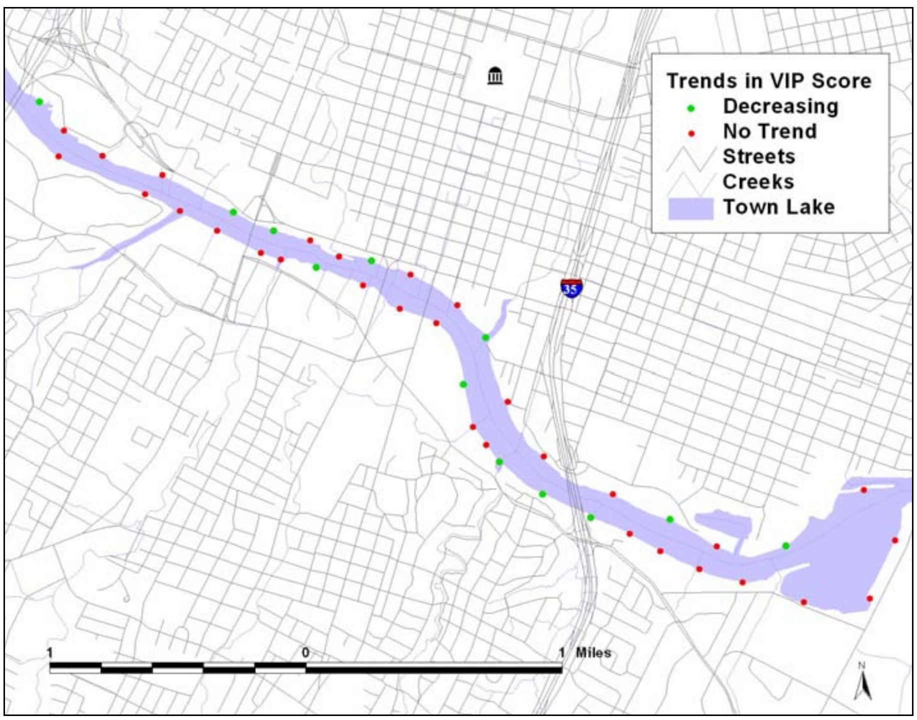


Figure 5.4. Town Lake VIP sites exhibiting decreasing temporal trends over time.

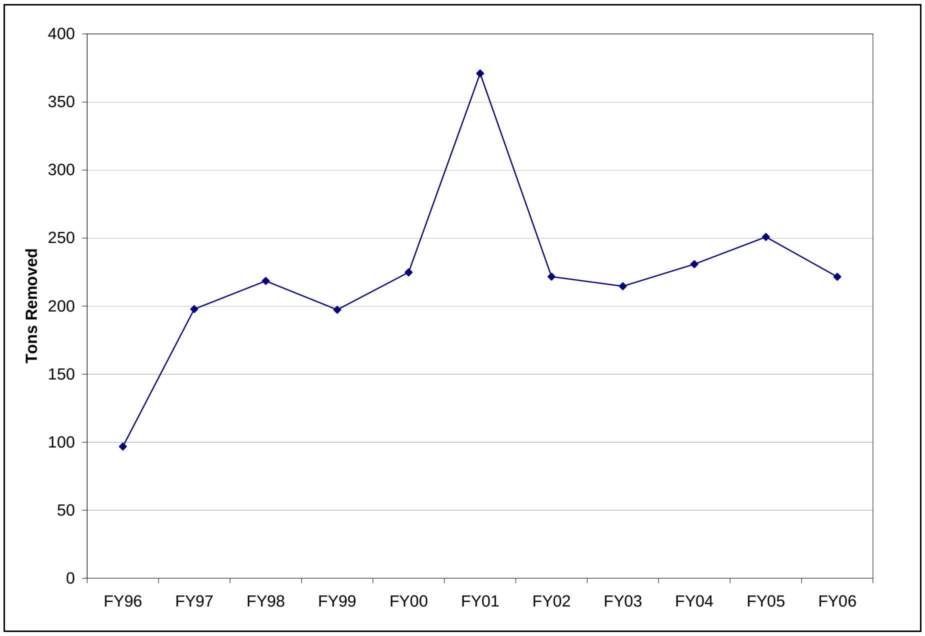


Figure 5.4. Tons of litter removed from Town Lake by fiscal year (1996-2006).

Long-term lake-wide quarterly average scores are significantly different by REGWQ means test ($p<0.0001$), with Q2 scores significantly lower than any other quarter (Figure 5.6). Similar seasonal effects with lower scores observed during months when more dense bank vegetation obscures shoreline trash was observed in previous analyses (COA 2004a).

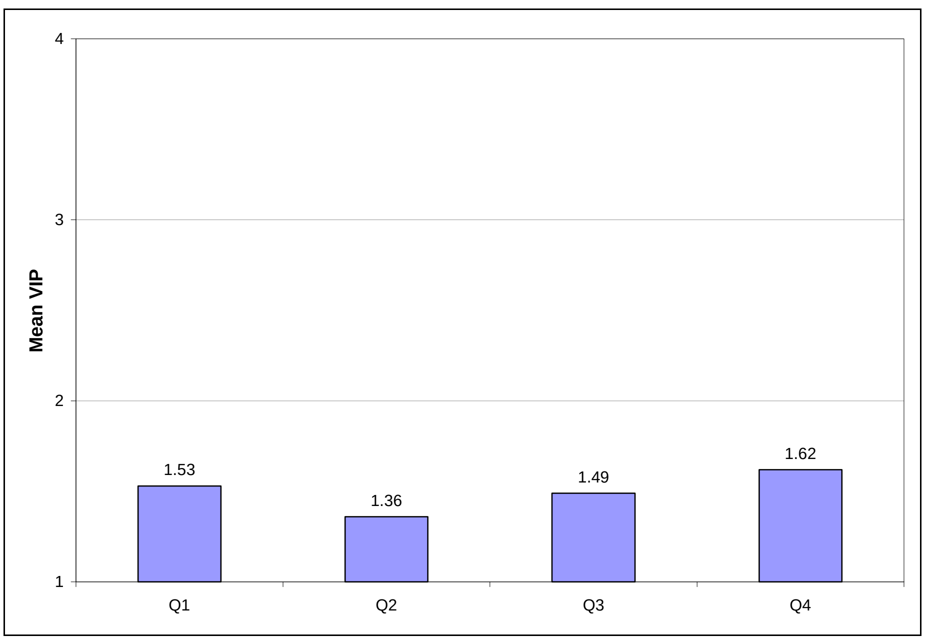


Figure 5.6. Quarterly average lake-wide VIP scores (1999-2006). Q2 scores significantly lower than all other quarters ($p<0.0001$).

Conclusions

Based on VIP scores, Town Lake is not degrading aesthetically. VIP scores are improving over time. Current litter management practices are sufficient to maintain lake-wide VIP scores less than 2 at current levels of litter deposition. To date, WEFOD has removed more than 2,445 tons of litter and debris from Town Lake.

The southern shore of Town Lake near IH-35 yields the worst VIP scores, although some of these areas are improving over time.

Recommendations

Current Town Lake aesthetic or biological monitoring programs do not include an assessment of aquatic or shoreline macrophyte composition or riparian vegetative buffer widths. This data may be useful in explaining observed variation in benthic macroinvertebrate communities between sites as well as serving as an independent measure of the Town Lake ecosystem integrity. A periodic riparian vegetation assessment as well as an assessment of the recreational or aesthetic quality of the lakeshore area could be added to current VIP monitoring.

6.0 Benthic Macroinvertebrates

Benthic macroinvertebrates are common inhabitants of lakes and streams where they are important in moving energy through food webs. Benthic macroinvertebrates are a highly diverse group, which makes them excellent candidates for studies of changes in biodiversity. Different groups of macroinvertebrates have different tolerances to pollution, and can serve as useful indicators of water quality. Biological monitoring provides an effective, easy-to-understand method for determining if a watercourse has been impacted by a pollution source. Macroinvertebrates may live from several weeks to many years and directly depend on adequate habitat and water quality for survival. As a result, macroinvertebrates can indicate pollution impacts from cumulative or multiple sources.

The Town Lake reservoir can be characterized as riverine from Tom Miller Dam to the IH-35 bridge where it widens and quickly transitions into the lacustrine basin area. Three representative sampling locations were selected (Figure 6.1). Although these sites do not directly coincide with water quality sampling locations, they are more representative of the potential benthic macroinvertebrate habitat divisions within Town Lake.

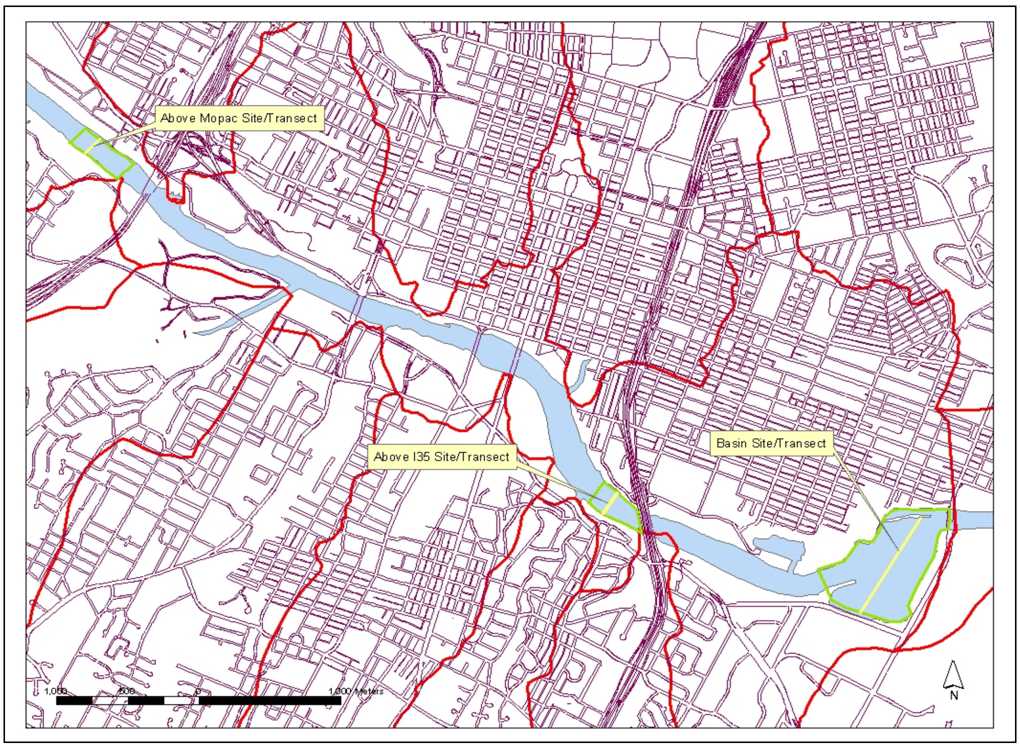


Figure 6.1. Benthic macroinvertebrate sampling locations.

COA samples of Town Lake benthic macroinvertebrates began in September 2004. Two different habitats were sampled at each site, once per release season targeting late summer (release) and late winter (non-release) months (Table 6.1). These time periods coincide with the critical, or most stressful period (warmest) in the summer and following insect recruitment but before major emergence in the spring.

Table 6.1. Summary of benthic macroinvertebrate sample dates included.

Non-Release	Release
September 2006 September 2005 September 2004	March 2007 March 2005

The littoral zone, or vegetated area where depths are less than 1 m deep, was sampled quantitatively with D-nets in as many habitats as occur in a band 6 m wide to the edge of the water (EPA 1998). The two resulting littoral samples (one per shoreline) were maintained discretely in the field, but the data was composited for analysis. Three staff people spent one minute each sampling one third of the sample area described above. The three samples were composited in one large container, cleaned of large, excess material and then distributed in a Caton gridded sub-sampler. Grids were removed and picked in the field entirely with a target of 200 organisms (+/- 20%). Following sorting/sub-sampling, an experienced taxonomist scanned the remaining detritus and all large and rare organisms were removed and placed in a discrete vial labeled "large/rare screen" for that site/habitat.

In the sub-littoral zone, or the area without significant vegetation, before shoreline mixing and with depths greater than 1 m, three Ponar dredge samples were collected on both the north and south sides of a lateral transect and composited. The three-sample composite was similarly sub-sampled and scanned for large/rare taxa.

Metrics were calculated by routine City of Austin (2004b) and TCEQ (2006) methods. Percent Trichoptera as Hydropsychidae was dropped from the analysis as all but two samples yielded zero values.

By Wilcoxon signed-rank test using matched pairs data to account for potential site and seasonal variation, there is no significant difference between the littoral samples collected from the north and south banks for any of the 21 individual metrics evaluated or TCEQ qualitative aquatic life use score. Sub-littoral samples were compared to average of littoral samples by site and date using Wilcoxon signed-rank test. The majority of metrics yielded a significant difference (Table 6.2), and only the percent of tolerant organisms was "better" in the sub-littoral zones (although the number of tolerant taxa was higher in the littoral habitats). Based on TCEQ aquatic life use scores (Harrison 1996), all sub-littoral samples yielded "limited" values and littoral samples ranged from "limited" to "intermediate." Although all littoral samples in year 2005 during the non-release were "limited," there were no other patterns in ALU scores between sites or seasons.

Table 6.2. Sub-littoral versus average littoral differences by Wilcoxon signed-rank test with mean difference (average littoral score minus sub-littoral score).

Metric	**(Avg Littoral) – (Sub-littoral)**	**Pr>|S|**	**Better in:**
# Diptera Taxa	0.5000	**0.0215**	Littoral
# Ephemeroptera Taxa	2.2667	**0.0004**	Littoral
# Intolerant Taxa	2.7000	**0.0001**	Littoral
# Non-Insect Taxa	4.4000	**0.0001**	Littoral
# of Organisms	153.8667	**0.0002**	Littoral
# of Taxa	11.0333	**0.0001**	Littoral
% Chironomidae	2.5753	0.3303	no diff
% Collector-Gatherer	-8.0520	0.1514	no diff
% Dominance (Top 1 Taxa)	-10.7537	0.0637	no diff
% Dominance (Top 3 Taxa)	-12.4370	**0.0015**	Littoral
% Dominant Guild	-3.4613	0.5245	no diff
% Elmidae	0.2677	0.0625	no diff
% EPT	7.0167	**0.0026**	Littoral
% Filterers	3.1510	0.4212	no diff
% Grazers	6.2417	**0.0001**	Littoral
% Predators	5.6907	0.1876	no diff
% Tolerant Organisms	0.8043	**0.0295**	Sub-Littoral
EPT Taxa Richness	2.9000	**0.0001**	Littoral
EPT/EPT+Chironomidae	0.2629	**0.0026**	Littoral
HBI	-0.5250	**0.0001**	Littoral
Ratio of Intolerant to Tolerant	0.1100	**0.0002**	Littoral
TCEQ ALU Score	3.6333	**0.0004**	Littoral

The majority of metrics yielded no significant difference between release and non-release seasons in the sub-littoral habitat samples by ANOVA. Only the number of diptera taxa, the percent chironomidae, and the percent filterers were different and all were higher in the non-release season from sub-littoral samples.

In the littoral zones, half of the evaluated metrics yielded no significant difference between the release and non-release seasons (Table 6.3). For metrics with significant differences, the release season generally yielded higher values. Some individual taxa such as *Hyallela* that were encountered in every sample yield higher average number of individuals in release than in non-release. Some taxa such as *Argia*, *Hydroptila*, *Polycentropus*, and *Epitheca* are only observed in release at the Basin and MoPac sites.

Table 6.3. Comparison of release and non-release seasons by ANOVA for littoral samples.

Label	Pr>F	Mean, Non-Release	Mean, Release	Better In:
# Diptera Taxa	0.4646	1.917	1.667	No difference
# Ephemeroptera Taxa	0.0001	1.917	4.278	Release
# Intolerant Taxa	0.0132	2.667	4.611	Release
# Non-Insect Taxa	0.5368	9.583	10.167	No difference
# of Organisms	0.0443	232.583	375.278	Release
# of Taxa	0.0011	16.250	23.000	Release
% Chironomidae	0.1603	22.367	14.858	No difference
% Collector-Gatherer	0.2070	58.939	67.917	No difference
% Dominance (Top 1 Taxa)	0.0081	38.399	54.144	Non-Release
% Dominance (Top 3 Taxa)	0.0984	67.684	74.080	No difference
% Dominant Guild	0.0165	62.483	73.206	Non-Release
% Elmidae	0.3264	0.026	0.462	No difference
% EPT	0.0001	4.000	12.837	Release
% Filterers	0.0524	31.170	19.125	No difference
% Grazers	0.0374	5.220	9.443	Release
% Predators	0.3210	31.927	25.728	No difference
% Tolerant Organisms	0.2194	1.565	0.914	No difference
EPT Taxa Richness	0.0002	2.667	5.722	Release
EPT/EPT+Chironomidae	0.0017	0.228	0.526	Release
HBI	0.1603	6.773	7.015	No difference
Ratio of Intolerant to Tolerant	0.6765	0.148	0.133	No difference
TCEQ ALU Score	0.0366	20.500	22.389	Release

Two-way Wilcoxon signed-rank tests were used to evaluate differences between sites controlling for differences by season and year. Metric scores exhibited very little variation between sampling locations. In both littoral and sub-littoral samples (analyzed separately), there was no significant difference between the Basin and MoPac for any metric. There were no differences between the Basin and IH-35 in the sub-littoral samples, and only number of non-insect taxa and number of organisms were significant different (higher) at the Basin versus IH-35 in the littoral samples.

For both littoral and sub-littoral samples, 6 of the 22 evaluated metrics including ALU score were significantly better at the MoPac site versus the IH-35 site. The IH-35 site has the lowest width of riparian buffer zone, and is the closest to storm drain outfalls from downtown Austin. The lack of difference between MoPac and the Basin indicates that the observed differences are most likely due to the reduction in riparian habitat at the IH-35 site, but could indicate some impairment at the IH-35 site with recovery at the Basin site.

Despite the small number of sampled years, metrics were analyzed for temporal trends by sample site accounting for seasonal and habitat differences by entering representative quantized variables into the regression model before year of sampling. Few temporal trends were observed at the IH-35 and Basin sites (Table 6.4), although the ALU score may be improving over time at IH-35. At the MoPac site, a decrease in the percent chironomidae and increase in percent collector-gatherer appears to be driving observed trends. There is no trend in ALU score at MoPac.

Table 6.4. Summary of significant temporal trends by sample site accounting for differences in season and habitat type.

MoPac	IH-35	Basin
Increasing: % dominant guild % collector-gatherer Decreasing: % predators % filterers % chironomidae	Increasing: # taxa ALU score	Increasing: # non-insect taxa Decreasing: Ratio of intolerant to tolerant

The applicability of metrics developed for lotic riverine habitats to Town Lake is questionable. Analyses of individual taxa or non-traditional metrics may be more appropriate for elucidating spatial differences or temporal trends. EPA (1998) guidance documents suggest several alternative metrics that respond to enrichment or DO stress including % oligochaetes, number of ephemeroptera-trichoptera-odonata (ETO) taxa, and % shredders.

Percent oligochaetes (number of oligochaete individuals as percent of total number of individuals) is expected to be elevated under organic enrichment. Percent oligochaetes yielded higher mean values in the non-release season at all sites and higher mean values at IH-35 than at Basin and MoPac.

Number of ETO taxa are expected to be reduced under enrichment, and shows a strong seasonal effect with lower number of ETO taxa in the non-release period. Higher number of ETO taxa are observed at the Basin during release.

The percent shredder metric in Town Lake is dominated by *Hyallela*, and thus primarily reflects patterns observed in evaluation of *Hyallela* between sites and seasons. Percent shredders is expected to be reduced under enrichment and may be affected by lake size. Percent shredders is generally higher during release, but yields varying differences between sites for the five sample dates. If variability in site differences can be correlated to observed patterns in water quality, percent shredders may useful as a temporally sensitive metric.

Conclusions

There is no difference between the north and south shore littoral samples. Littoral habitats generally yield higher (better) metric scores than sub-littoral habitats.

Sub-littoral samples yield few differences between seasons. Higher mean scores are observed during the release season in littoral samples for approximately half of the metrics evaluated. Contrary to patterns observed in Austin-area stream benthic macroinvertebrate populations that are most stressed in the warmest late summer months when flows are at a minimum, Town Lake benthic macroinvertebrates may be more stressed at the end of the winter/spring low-flow non-release season despite cooler temperatures (as long as samples are collected prior to spring insect emergence). Release conditions may be representative of best attainable conditions when evaluating Town Lake benthic macroinvertebrate community integrity using typical stream metrics.

There are few differences between metric scores at the sampling locations. Observed differences are most likely due to riparian habitat differences, but could indicate impairment at the IH-35 site with recovery at the Basin site.

There are few temporal trends in metric scores, although IH-35 may be improving in ALU score over the period of study and a functional shift driven by increasing collector-gatherer and decreasing chironomidae may have occurred at MoPac.

Recommendations

COA biological monitoring staff need to determine what metrics are most appropriate for evaluation of Town Lake benthic macroinvertebrate samples. A best attainable condition should be established as a reference using existing data combined with professional judgment (EPA 1998) for evaluation of future samples.

Unless worthwhile individual taxa differences can be found using the sub-littoral data, the sub-littoral sampling can be discontinued as the littoral samples appear to represent best attainable conditions for a given site.

Tennessee Valley Authority reservoir sampling found that late winter/early spring sampling was not acceptable because results reflected conditions of the previous year and were not synchronized with other indicators (EPA 1998). Conditions in Town Lake are strongly affected by dam operations, and the early spring sample at the end of the non-release season could more accurately integrate the periods of reduced DO and minimum flows. Depending on monitoring goals, COA staff should determine if it is more appropriate to represent benthic macroinvertebrate community integrity at the best attainable or most impacted conditions (or both) for future sampling efforts.

Due to lack of observed differences between sites, the number of sites could be reduced, particularly in favor of increasing frequency in a specific season to quantify natural variability. Documentation of the general lack of difference between sampling locations in Town Lake could be useful in the future for determining localized changes in non-point source impacts. Similar to sample frequency, the choice of sample sites should reflect a desire to represent best attainable (MoPac or the Basin) or most impacted (IH-35) conditions.

7.0 Phytoplankton

Phytoplankton, as the base of the aquatic food chain, most readily integrate chemical and physical conditions in addition to influencing other lake biota (Reynolds 1984, Muscio 2004). Relationships between ambient conditions and nutrient concentrations and the associated effects on algae growth in Town Lake have been previously examined in detail and well described using the Water Quality Analysis Simulation (WASP) model (COA 1992, COA 2000). While it is not necessary to repeat these analyses, evaluation of the trophic status of Town Lake since the last report is warranted as the Austin Water Utility staff continue to collect phytoplankton grab samples from the Green, Davis, and Ullrich water treatment plant (WTP) intakes on a semi-weekly basis. The Green WTP is located on Town Lake near the mouth of Shoal Creek; the Ullrich WTP is located on Lake Austin near the mouth of Bee Creek, just upstream of the Tom Miller Dam.

The AWU algae counts are generated from a mixed whole water grab sample and identified in a Sedgewick Rafter cell by method 10200F (APHA 2005) at 200x magnification to division: chlorophyta (green), cyanophyta (blue-green), chrysophyta (diatom), flagellate algae. The counts are performed on natural units, where colonies and filaments are counted as one organism. Though consistently measured over time, the natural unit count under represents the colonial and filamentous green and blue-green algae (Muscio 2004).

Previous Town Lake analyses (COA 1992, COA 2000) have classified the trophic status of Town Lake using the regular algae count data (Table 7.1), based in part on relationships to literature values for chlorophyll-a (Olen 1990). Algae blooms on Town Lake were defined when the total plankton counts exceeded 15,000 cells/mL. More recent analyses (Muscio 2004) have suggested defining blooms based on a pre-determined number of standard deviations of the long-term means for the specific algal divisions reported.

Table 7.1. Relationship between phytoplankton measures and trophic status (COA 2000).

Trophic State	oligotrophic	mesotrophic	eutrophic	hyper eutrophic
chl-a (µg/L)	<4	4-10	10-25	>25
plankton (cells/mL	<2,000	2,000-15,000	>15,000	

Spatial Comparison

During two routine water quality sampling events in 2005, COA staff collected phytoplankton samples from the routine sampling locations for comparison to AWU counts as a measure of the spatial variation within Town Lake (Table 7.2). Although COA samples were collected from a boat in mid-channel while AWU samples are collected from the shoreline, samples were analyzed similarly to AWU methods. While spatial differences are evident, there are not enough samples to determine if patterns are temporally consistent or predictable.

Table 7.2. Comparison of counts from two sampling events from routine sampling locations to AWU counts at the Green WTP.

Date	Parameter	Basin	First	RedBud	Green
24-Oct-2005	ALGAE BLUE-GREEN	163.2	40.8	61.2	61
24-Oct-2005	ALGAE FLAGELLATE	3325.2	1081.2	856.8	1300
24-Oct-2005	ALGAE GREEN	102.0	0.0	0.0	20
24-Oct-2005	DIATOM COUNT	61.2	61.2	122.4	140
24-Oct-2005	PLANKTON	3651.6	1183.2	1040.4	1600
07-Nov-2005	ALGAE BLUE-GREEN	61.2	40.8	102.0	41
07-Nov-2005	ALGAE FLAGELLATE	877.0	2244.0	2366.4	2600
07-Nov-2005	ALGAE GREEN	102.0	20.4	122.4	41
07-Nov-2005	DIATOM COUNT	428.4	367.4	142.8	140
07-Nov-2005	PLANKTON	1468.6	2672.6	2733.6	2800

Counts at the Green WTP can be compared to Lake Austin counts from the most downstream Lake Austin plant, Ullrich WTP, as a measure of the effects of Town Lake on upstream algal inputs. Based on approximately 1,400 paired observations from 1992 to 2006, Lake Austin maintains higher plankton counts than Town Lake by paired Wilcoxon signed-rank test (Figure 7.1). When separated by season, however, mean flagellate and total plankton counts are quantitatively higher in Town Lake but median counts are higher in Lake Austin. This is consistent with historically observed patterns (COA 2000). Lake Austin is primarily in the mesotrophic state, while Town Lake has historically varied from the oligotrophic to mesotrophic states during non-bloom conditions.

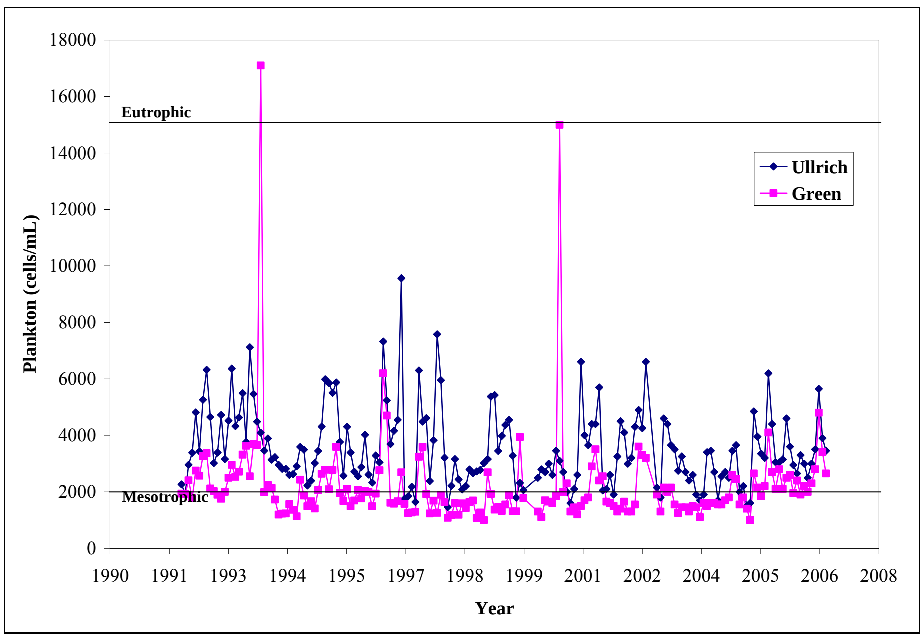


Figure 7.1. Monthly median total plankton counts from AWU in Town Lake (Green WTP) and Lake Austin (Ullrich WTP).

Trophic Status

Based on chlorophyll-a concentrations (Figure 7.2) differences in algae growth between sites are clearly evident, with Red Bud typically remaining in the oligotrophic state but both First and Basin peaking into the hyper-eutrophic state during bloom periods. The percentage of time based on chlorophyll-a data that the Town Lake is oligotrophic is decreasing in favor of an increase in the percentage of time in a mesotrophic state. However, sampling frequency and targeted months have changed over time. Thus, trophic status is more appropriately characterized by the regular AWU algae counts.

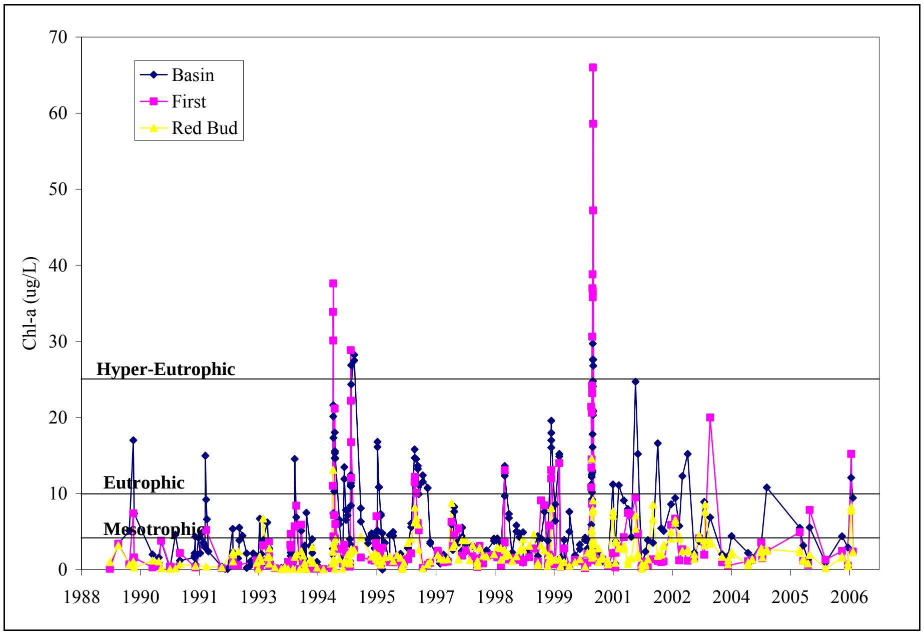


Figure 7.2. Chlorophyll-a concentrations with trophic status (COA 2000).

Using AWU total plankton counts, the number of algae blooms per year over time was compared using both the traditionally defined count levels (COA 2000) and two alternative bloom definitions suggested as the period of record mean (2,682 cells/mL) plus one standard deviation (5,804 cells/mL) of the mean (Muscio 2004). The number of algae bloom periods per year is decreasing over time from 1990 to 2006 by linear regression for the bloom definition based on the historical mean plus one standard deviation ($p=0.0140$, $r^2=0.34$) and for the traditional definition ($p=0.0073$, $r^2=0.39$).

Table 7.3. Number of bloom periods by year over time by traditional definition (COA 2000) and alternative definition (Muscio 2004).

Year	**# sample days**	**# blooms (COA 2000)**	**# blooms (Muscio 2004)**
1990	169	3	5
1991	203	1	4
1992	192	0	0
1993	230	2	9
1994	230	2	7
1995	235	2	5
1996	248	0	1
1997	213	0	1
1998	200	0	1
1999	229	1	4
2000	164	1	3
2001	224	1	4
2002	176	0	0
2003	251	0	0
2004	230	0	0
2005	234	0	1
2006	242	0	0

There is no linear temporal trend in mean monthly plankton count or median monthly plankton count over the period of record. Examination of the percentage of time by year in the varying trophic states using the traditional definition (COA 2000) compared to monthly median counts indicates that the periods of 1991-1993 and 2005-2006 were more enriched with less than 50% of months yielding monthly median counts in the oligotrophic state (Figure 7.4). There is no trend in the percentage of time by year in the oligotrophic or mesotrophic states using the raw daily counts from Green WTP (Figure 7.5). Percentage of time in each of the trophic states does not appear to be related to the number of days in release season by year.

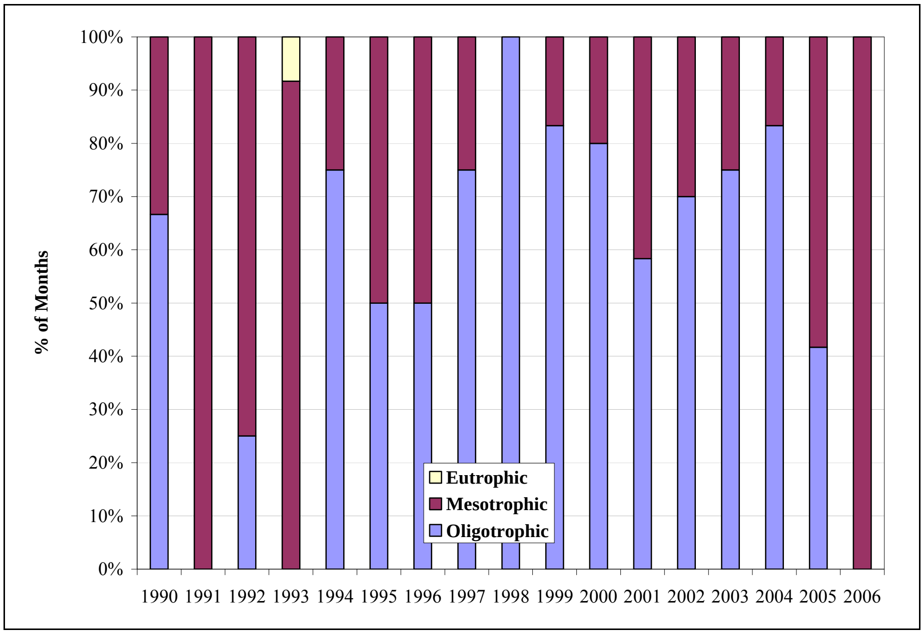


Figure 7.4. Percent of year with Town Lake monthly median total plankton counts in the oligotrophic (<2000 cells/mL), mesotrophic (2000-15000 cells/mL) and eutrophic states (>25000 cells/mL).

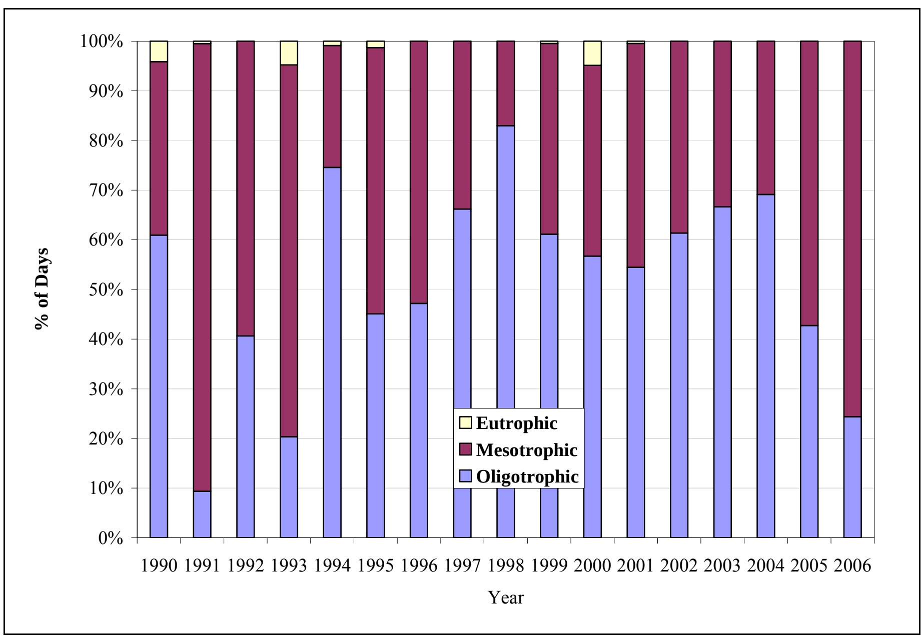


Figure 7.5. Percent of daily counts by year in the oligotrophic (<2,000 cells/mL), mesotrophic (2,000-15,000 cells/mL) and eutrophic (>15,000 cells/mL) states.

Blooms for the individually measured algal divisions identified in the AWU algae counts were defined as sets of one or more consecutive days with counts exceeding the mean plus one standard deviation (Figure 7.6). Flagellate algae, which dominate the natural unit counting method used by AWU (Muscio 2004), closely follow observed patterns in total counts as expected and have not bloomed since 2001. Like the total algae counts, flagellate algae blooms are decreasing over time.

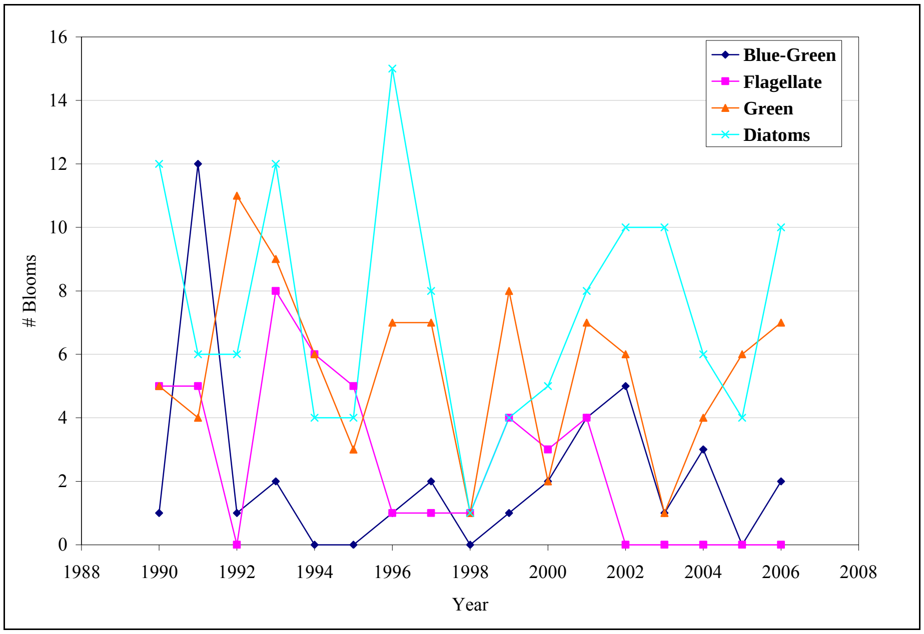


Figure 7.6. Number of blooms by division identified by AWU in the counts from the Green WTP.

Diatoms and green algae are more likely than flagellate or blue-green algae to bloom in any given year, yielding averages of 7 and 5 blooms per year since 1990, respectively, and blooming in years with no total plankton count blooms. There is no correlation between number of blooms per year for any division.

Based on available data identified to genus, blue-green algae in Town Lake are most likely *Oscillatoria* according to the AWU counting method. *Anacystis* are the next most frequently encountered blue-green genera, followed by *Phormidium* and *Anabaena*. Flagellate algae and diatoms are not typically identified to genus by AWU. Green algae blooms are typically *Scenedesmus* or *Tetraedron* blooms. *Scenedesmus*, *Ankistrodesmus*, and *Tetraedron* are the most typically encountered green algae genera during non-bloom conditions.

Blue-green blooms are more likely to occur in the release season, and overall blue-green algae blooms are short (approximately 1 day) although bloom periods as long as 45 days (in 1996 during release) have been observed. The duration of blue-green blooms in the non-release period may be increasing over time (p=0.06) due to extended blooms observed in 2004 and 2006.

Flagellate algae are more likely to bloom in the non-release season, and blooms are typically longer in duration than blue-green algae blooms (approximately 2.4 days) though the maximum duration (9 days in 2000 in non-release) was much shorter than the maximum blue-green algae bloom duration.

Green algae and diatom blooms are more likely to occur during release, but occur in both seasons. Green algae blooms as long as 30 days (1996) have occurred in the release season, although a 19 day bloom in the non-release season occurred in 2006.

Long duration algae blooms are typically composed of multiple algal divisions blooming, not just a single division. Long duration algae blooms are more likely to result in depressed DO at depth (near anoxic levels) in the Basin than shorter duration algae blooms, as expected, although on multiple occasions depressed DO values have been recorded following short duration algae blooms. Low DO at depth events have been recorded when no algae bloom was observed, although these events are exclusively restricted to the warm months of July, August and September. Algae blooms have occurred when no associated DO impairment has been registered in ambient monitoring data. DO impairments from algae blooms may be partially mitigated or amplified by other factors such as antecedent flow or ambient temperature. Quantification of algal biomass and associated growth rates may be necessary to gage the relative potential impacts of the individual algal divisions on DO.

Use of the standardized Carlson (1977) Trophic State Index (TSI) based on the chlorophyll-a, total phosphorus, or Secchi disk depth measurements allows for estimation of the trophic status of Town Lake on a scale from 0-100 (most oligotrophic to most eutrophic) that can be directly compared to other reservoirs and not subjected to varying definitions of the oligotrophic-mesotrophic and mesotrophic-eutrophic boundaries. TSI values were calculated for each component at each routine monitoring site during non-storm conditions using nutrient data collected at surface depths (Figure 7.7).

TSI values may be calculated individually for either chlorophyll-a, total phosphorus and Secchi disk depth or calculated for all three and compared as a check on the underlying assumptions of the Town Lake ecosystems as the individual components should yield the same TSI value. The divergence of the TSI values for phosphorus and chlorophyll-a indicates that at times either phosphorus is not the limiting nutrient for Town Lake phytoplankton or some factor other than nutrient availability limits Town Lake phytoplankton growth. Additional non-volatile suspended solids (not phytoplankton biomass) in Town Lake may account for the more eutrophic TSI values for Secchi disk depths relative to biomass TSI values (chlorophyll-a).

Over the period of record, chlorophyll-a TSI values are increasing (becoming more eutrophic) over time at all sites. Phosphorus TSI values are increasing over time at Basin and Red Bud. Secchi disk depth TSI values are decreasing (becoming more oligotrophic) over time at Red Bud. Since January 2000, however, chlorophyll-a TSI values are actually decreasing over time at Basin and First Street, phosphorus TSI values are decreasing over time at all sites, and Secchi disk TSI values are decreasing over time at First Street.

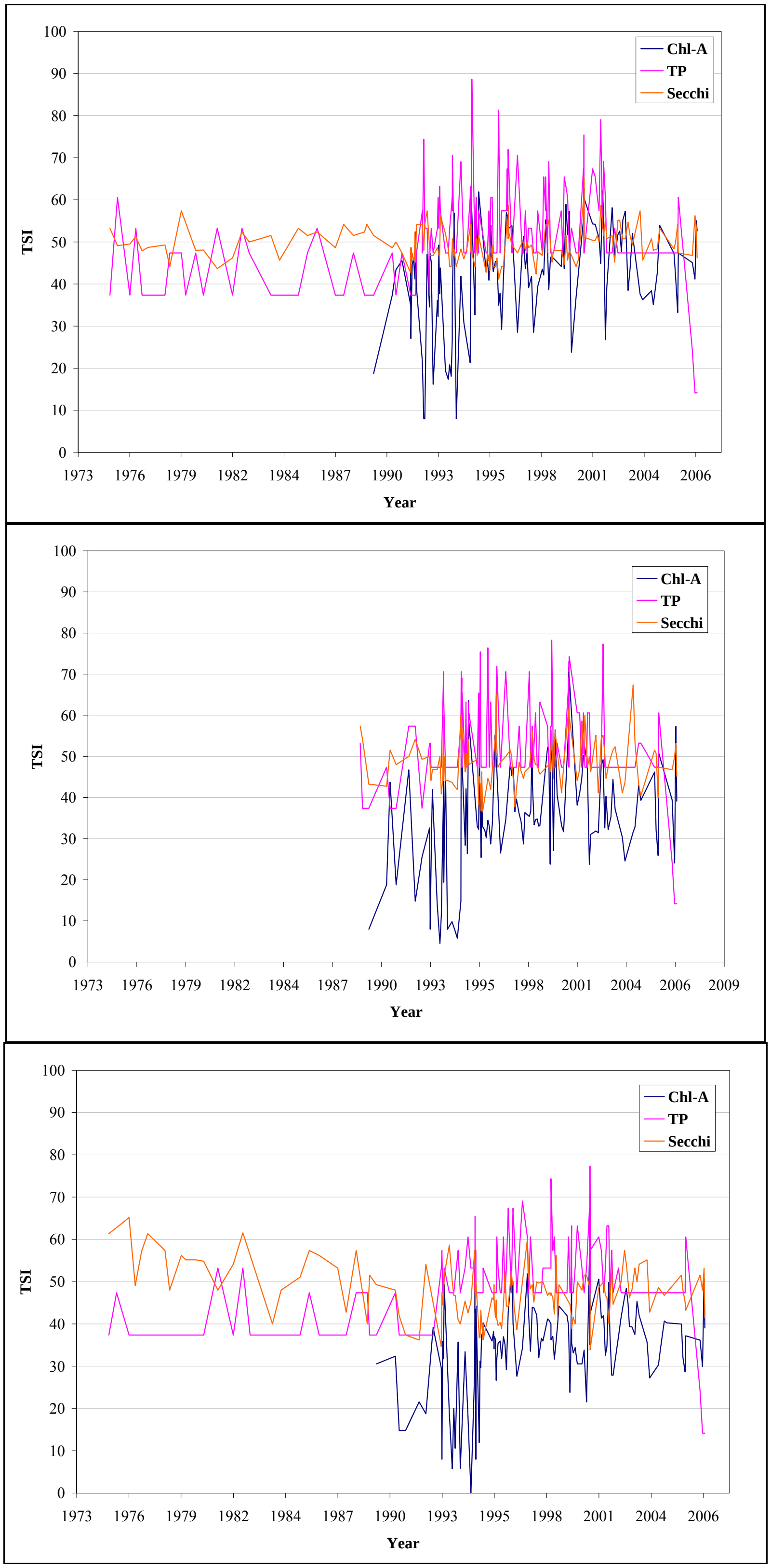


Figure 7.7. Carlson TSI values for chlorophyll-a, total phosphorus and Secchi disk depth at Basin (top), First (middle) and Red Bud (bottom).

Based on chlorophyll-a TSI scores over the period of record, the non-release season on average yields approximately double the algal biomass as the release season at the Basin and First Street sites, but algal biomass is not significantly different between seasons at Red Bud. Conversely, Secchi disk depth TSI scores are not different between seasons at the Basin and First Street sites, but the release season yields higher (more eutrophic) TSI values than non-release at Red Bud. The relationship between real measured Secchi disk depth and chlorophyll-a at the Red Bud site also does not follow expected patterns demonstrated at the First Street and Red Bud sites (Figure 7.8). Secchi disk depths may be more affected at Red Bud by non-volatile suspended solids input from Lake Austin than algal biomass accumulation.

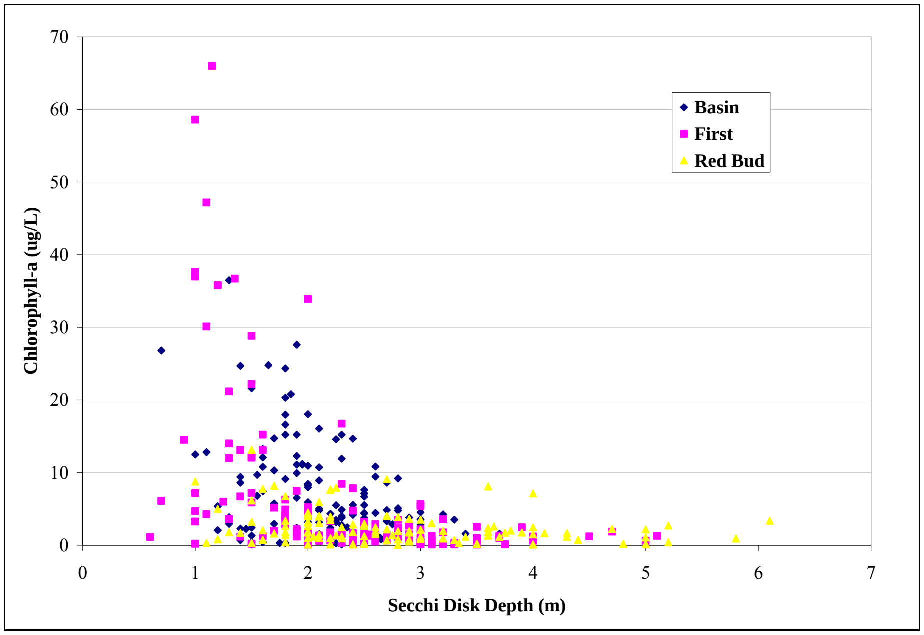


Figure 7.8. Non-linear inverse relationship between chlorophyll-a and Secchi disk depth during non-storm flow by sample site.

Monthly patterns in average TSI values over the period of record show general agreement between Secchi disk and total phosphorus TSI values (Figure 7.x). Chlorophyll-a TSI scores are consistently lower. Some divergence of chlorophyll-a scores from total phosphorus scores is expected during spring months due to algal population crashes, although chlorophyll-a concentrations are consistently lower especially during summer months and the differences are less pronounced at the Basin. It is possible that a flow effect, less pronounced at the most lacustrine site, may be limiting actual algal biomass production. A flow limitation on chlorophyll-a biomass is supported in part by the observed seasonal differences.

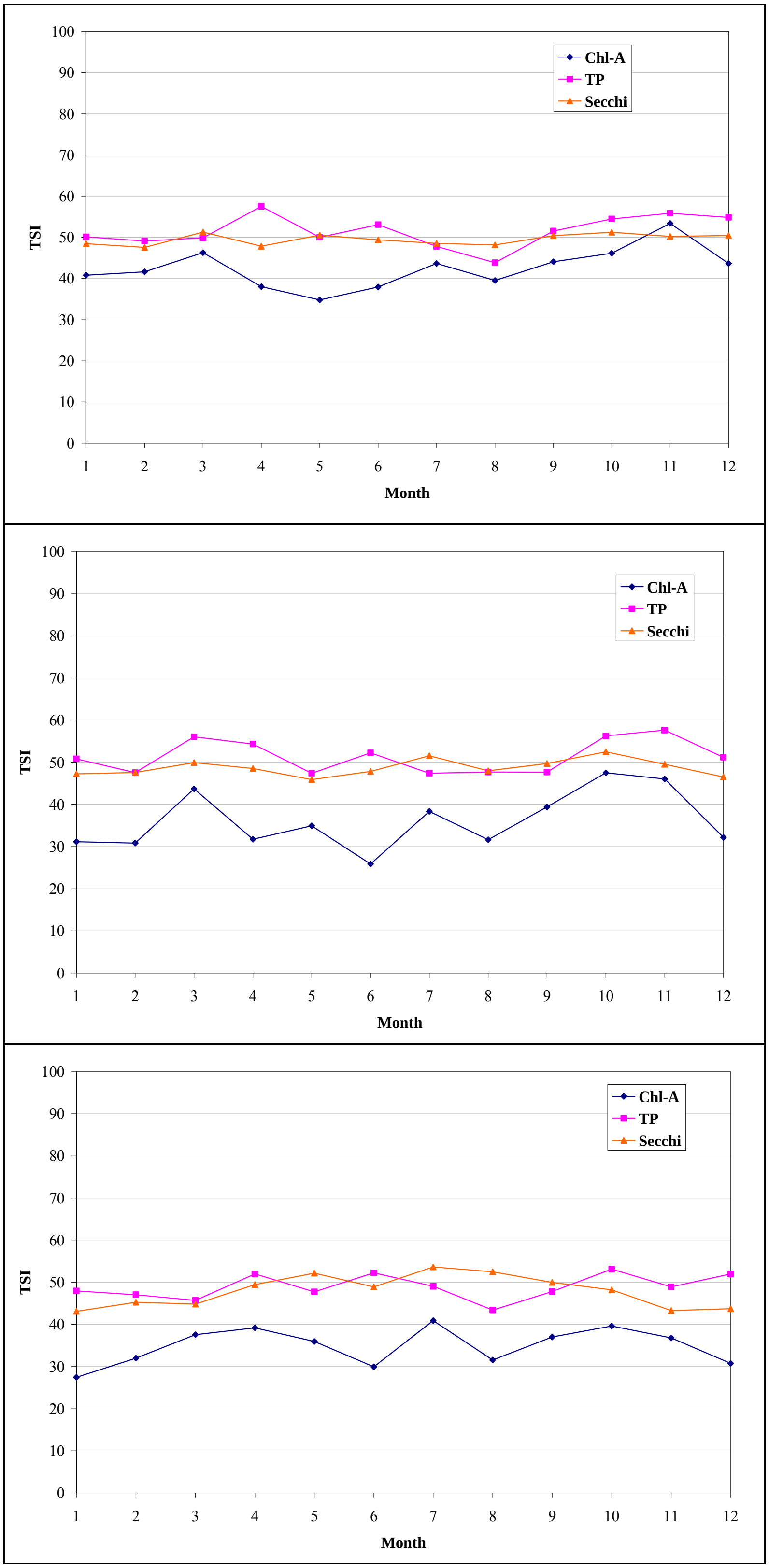


Figure 7.8. Monthly average TSI scores at Basin (top), First (middle) and Red Bud (bottom).

Limiting Nutrient

Comparison of the molar ratio of nitrogen to phosphorus can be used to determine the limiting nutrient based on ecological stoichiometry. The expected nitrogen to phosphorus atomic ratio in most phytoplankton without nutrient limitation is 16:1 (Redfield 1958), although this ratio may vary for different algal taxa (Rhee and Gotham 1980). Studies of river phytoplankton have estimated that Redfield ratios above 20 suggest phosphorus limitation (Schanz and Juon 1983). Total nitrogen and phosphorus ratios were calculated for each surface sample on Town Lake and evaluated over time by sample location.

Both mean and median Redfield ratios at each site during any flow and release condition are greater than 35, suggesting that at all times Town Lake phytoplankton growth is most likely phosphorus-limited.

Comparison of Redfield ratios between sites by Wilcoxon signed-rank test indicate that ratios are higher at First Street than Red Bud and the Basin but not different between Red Bud and the Basin (Figure 7.9). Elevated ratios at First Street are most likely due to Barton Springs nitrate loads.

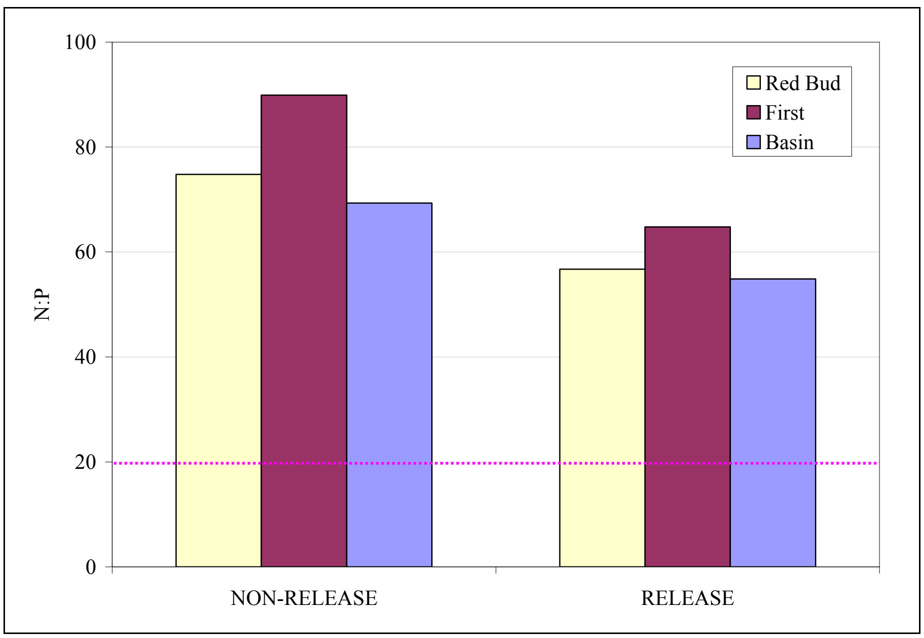
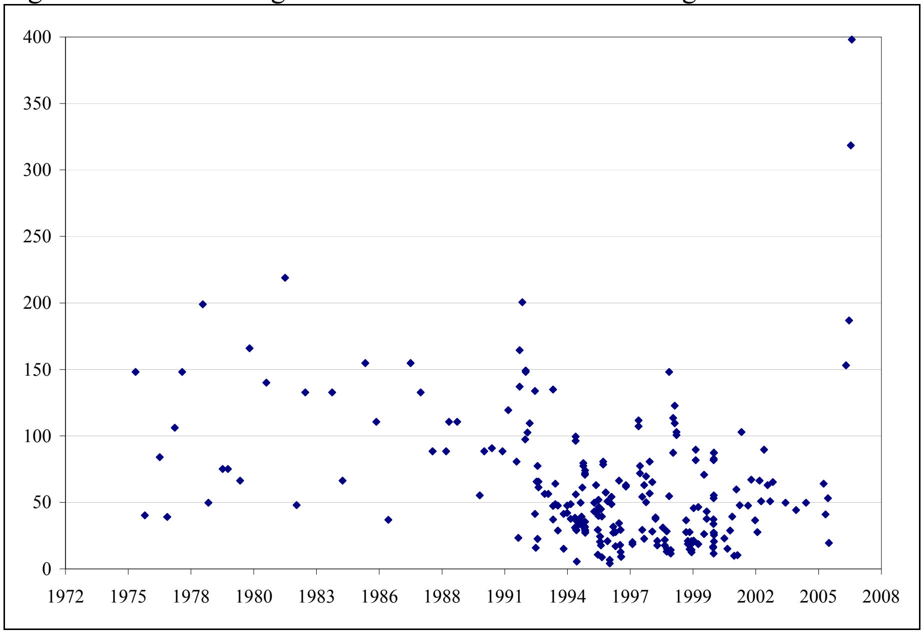


Figure 7.9. Average Redfield ratios by site and season during non-storm flow conditions since January 2000 with the 20:1 ratio indicating phosphorus limitation (pink).

During non-storm flow and accounting for seasonal and analytical lab differences, Redfield ratios are decreasing over time at all sites using all data or using only data collected since January 2000 (Figure 7.10). Though decreasing over time and highly variable, the percentage of samples with Redfield ratios greater than 20 remains above 80% at all sites.

Figure 7.10. Decreasing Redfield ratios at the Basin during non-storm flow over time.



Conclusions

Lake Austin continues to maintain higher baseline algae concentrations, particularly during the release season when Town Lake algae counts are lower. For the majority of the period of record Town Lake is in an oligotrophic state for at least 50% of the year based on monthly median counts, although recent data from 2005 and 2006 were more enriched and primarily mesotrophic.

Flagellate algae bloom frequency is decreasing over time but there are no trends in the percentage of time that Town Lake is in the oligotrophic or mesotrophic states based on the total AWU plankton counts. Although Carlson TSI values indicate that Town Lake is becoming more eutrophic when the entire period of record is considered, TSI values show an improvement (less eutrophic) using only data collected since January 2000.

Blooms of individual blue-green, green and diatom algae may occur even though the total plankton count from AWU does not register a bloom due to the use of the natural unit counting method. Long duration algae blooms typically are comprised of blooms of multiple algal divisions. DO impairments from algae blooms may be partially mitigated or amplified by other factors such as antecedent flow or ambient temperature.

Green algae and diatoms are more likely to bloom in any given year than blue-green or flagellate algae. Blue green, diatom and green algae blooms are more likely to occur in the release season, although the duration of blue-green blooms during non-release may be increasing over time. Flagellate algae blooms are more likely to occur in non-release.

As expected from historical analyses, Town Lake is more eutrophic at the Basin and First Street sites during the non-release season based on Carlson TSI values for chlorophyll-a. Influx of non-volatile suspended solids may be limiting algal growth at Red Bud. Algal biomass may be limited by factors other than nutrient limitations including flow and suspended solids. Improvements in Town Lake clarity from improved structural and non-structural best management practices could actually increase Town Lake algal growth.

Town Lake phytoplankton growth continues to be primarily phosphorus-limited. Decreasing nitrogen to phosphorus ratios over time indicate the potential for an increase in Town Lake phytoplankton growth if ratios become more balanced (i.e., less limiting) in the future. Based on TSI values, there are periods when chlorophyll-a biomass growth may be limited by a factor other than nutrient availability.

Recommendations

Continue monitoring of algae by AWU methods at routine water quality sampling locations to test for spatial patterns in distribution of algae. Explore quantification of algal biomass by direct measurement or using nominal literature values and associated potential growth rates to more accurately quantify biomass density (than the current natural unit method) and gage the relative potential impact of division-specific blooms on Town Lake.

Use phytoplankton growth potential bioassays (Kiesling et al 2001, Herrington and Scoggins 2006) to measure trophic status of Town Lake using the Lotic Ecosystem Trophic Index over time and in varying conditions. In combination with growth potential bioassays, measure phytoplankton productivity using the light-dark bottle test, method 10200J (APHA 1995, Herrington and Scoggins 2006, Kiesling et al 2001), over time and in varying conditions. These methods can more accurately gage the trophic status of Town Lake phytoplankton and the potential daily DO flux in Town Lake due to phytoplankton photosynthesis and respiration.

Determine if it is necessary to continue to receive genera-specific data from AWU counts as only division totals are currently being transferred to WRE staff. If genera level data are useful, make arrangements to at least obtain hard copy bench sheets from AWU staff. Genera level data could be evaluated using a multi-metric similar to those employed for benthic macroinvertebrate analyses (EPA 1998).

8.0 The Town Lake Index

There is a need for a unified index to succinctly summarize the overall condition of Town Lake in any given year. As an exploratory analysis, a potential index has been developed incorporating the results of the analyses in this report.

Any descriptive Town Lake Index (TLI) must consider the general quality of the lake from multiple perspectives, and must be easy to communicate to the general public like the Environmental Integrity Index, or EII (COA 1997). Once developed, the TLI can be used not only to integrate and standardize analyses of data from multiple sources over time, but also as a target for measuring the effectiveness of City of Austin regulations and best management practices.

Data to be considered in this draft TLI include components that describe the aesthetics, ecology, water quality, and sediment quality according to varying weights (Table 8.1), which may be changed by decision-makers over time to represent changing public priorities. Similar to the EII, the TLI will be reported as a score ranging from 0 to 100 (worst to best). The TLI will be calculated as a weighted average of the selected component scores (Table 8.1).

Table 8.1. Description of Town Lake Index (TLI) components.

Subindex	Weight	Components
Trophic status	0.250	AWU algae counts
Water quality	0.225	Routine water quality data
Sediment quality	0.225	Routine sediment data
Aesthetics	0.200	Visual Index of Pollution
Biology	0.100	Benthic macroinvertebrates

Unlike the EII, however, the proposed Town Lake Index does not directly consider contact recreation or several other factors (Table 8.2). These factors could be included in the future if necessary to reflect changing public or regulatory interests.

Table 8.2. Factors not included in the Town Lake Index.

Category	Reason for Exclusion
Contact Recreation	Swimming is prohibited by ordinance except during permitted special events
Physical Integrity	Town Lake shorelines are generally stable and not affected by mass wasting or erosion
Flow	Flows are managed by LCRA through dam releases, and while increasing flows may dilute pollutants and decrease hydraulic residence time, COA staff have little to no influence over dam releases
Fish (Nekton)	No advisories currently apply to the consumption of Town Lake fish and there is no monitoring of nekton community composition or tissue burden
Macrophytes	Nuisance macrophytes are not as problematic on Town Lake as Lake Austin, and currently do not adversely affect aesthetics or recreation
Bathymetry	Bathymetric data is not collected on a regular basis
Riparian Vegetation	Quantity and quality of Town Lake riparian vegetation is not currently measured on a regular basis.

The TLI is intended to be calculated on an annual basis, using data that continues to be collected and generally has a long period of record. While the approach used here differs from the standard application of a multi-metric index, it is well suited for the type of routine monitoring data available for Town Lake and generally consistent with the EII methodology.

If a component cannot be calculated in a given year (data is missing or was not collected), then that component is not included and the score continues to be reported on the 100-point basis (using weighted-average). Component scores greater than 100 or less than 0 for any index are trimmed to 100 and 0, respectively.

Trophic Status Component

The trophic status component is calculated as the percent of AWU total plankton count samples in the oligotrophic state (<2,000 cells/mL) per year, normalized by the maximum percentage recorded since regular monitoring began in 1990 (83% recorded in 1998).

$$\text{Trophic Status Component} = ([(\text{\# oligotrophic counts}) / (\text{\# counts})] / 0.83)*100\%$$

Aesthetic Component

The aesthetic component is calculated using the average of the lake-wide quarterly VIP scores, adjusted to a 100 point scale so that an unacceptable VIP score of 2 will yield a failing (<70) index score. By this method, the maximum attainable score is 95 and the minimum is 20. This method should only be used for VIP data collected by current methods (data since 1999).

$$\text{Aesthetic Component} = [(\text{Average quarterly VIP score})*(-25)]+120$$

Benthic Macroinvertebrate Component

As Town Lake is an artificial reservoir, there is no in-lake reference site for evaluation of metric scores and comparison to pre-impoundment conditions as represented by the Colorado River downstream of Town Lake is no longer relevant. Thus, a best observed condition generated by professional judgment must be used as a reference condition for gauging impairment. An additional factor hampering the creation of a benthic macroinvertebrate multi-metric index is the lack of historical observations to gauge the impact of recent anthropogenic activities on Town Lake macroinvertebrates.

Based on current analyses, the release season for any given year can be considered to be the best observed condition of benthic macroinvertebrates for that year, whereas the non-release condition can be considered to be the impaired condition arising after the winter season of reduced DO and flow. The difference between the release and non-release seasons is representative of the impact of the most biologically stressful period of a year, similar to the TCEQ defined critical period for freshwater streams (TCEQ 2006). While accounting for climatic variation between years, the major disadvantage of the difference approach is that long-term impairments to the biota that depress both the release and non-release conditions are excluded. Thus, the difference should be inflated to reflect current difference from the maximum (best observed) release condition values. Only littoral samples will be included. Component scores will only be calculated for non-release samples.

Principal component analysis was used to identify highly correlated metrics. Candidate metrics for each group of correlated metrics that exhibited difference between release and non-release condition, temporal trends, and/or differences between sites were identified (Table 8.3). Metrics reported as percentages for which higher values represent a more degraded condition were "flipped" by subtracting the metric scores from 100 percent.

Table 8.3. Candidate metrics for benthic macroinvertebrate index.

Candidate Metrics	
% EPT	# Taxa
% Grazers*	Tolerance Ratio
% Dominant Taxa (3)*	# Organisms
% Filterers*	# Non-Insect taxa
% Chironomidae*	
% Oligochaete*	

*indicates reversed scale: higher values are more degraded

The benthic macroinvertebrate component was then calculated for each year as:

Benthic Component = average of non-release site scores in year

site score = average of selected metric scores per event
metric score = ((value in NR) / (Max value in any Release)) * 100%

Sediment Quality
The sediment quality component of the TLI is calculated according to the same method used for the EII (COA 1997), to aid in comparisons between creek and receiving water sediments. EII sediment scores are based on the values of chlordane, PCBs, metals and PAHs relative to biological effect levels. Only data from the Basin is evaluated. Sampling conducted by the USGS is included. Sediment component scores are calculated for each sampling event, then averaged for each year.

Water Quality
Similar to the sediment quality component, the water quality component is calculated by the same methods used in the EII (COA 1997) for direct comparison to creek water quality conditions. EII

water quality scores are based on the values of nutrients, conductivity, bacteria, and TSS. The Town Lake water quality scores are calculated by sample site and date using only non-storm flow data at all depths. Scores for each event are averaged by date, and date averages are averaged by year to yield annual water quality component scores.

Results

Component scores are variable, and the trophic status component yields the highest variability between years (Figure 8.1). Aesthetic and benthic macroinvertebrate scores are improving over time.

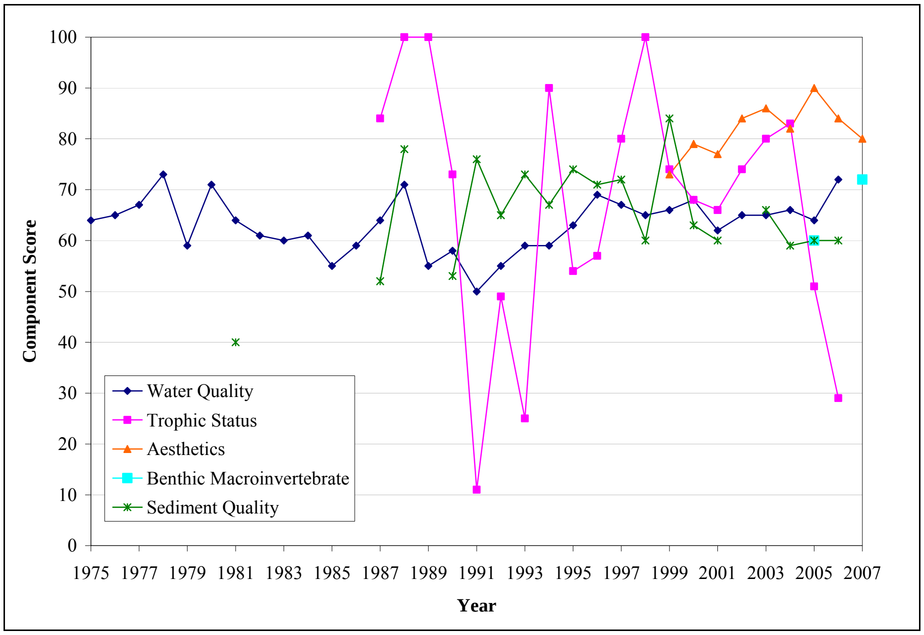


Figure 8.1. Town Lake Index individual component scores by year over time.

Town Lake Index scores over the period of record vary from 44 to 84, with a mean score of 66 (Figure 8.2). Using the EII narrative score categories (COA 1997), Town Lake mean TLI values would be classified as “good.” TLI scores are increasing over time, though the increase is not statistically significant by linear regression ($p=0.11$).

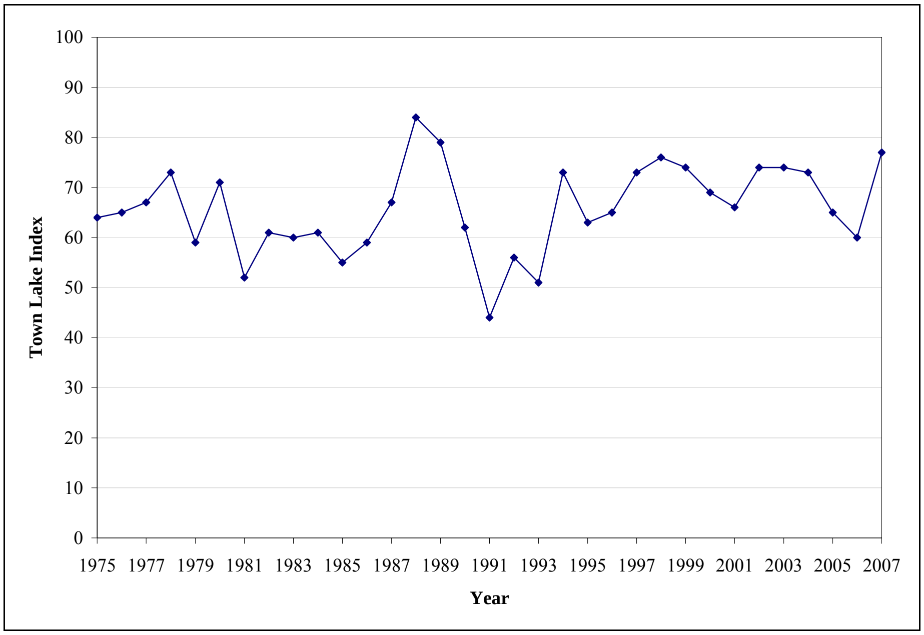


Figure 8.2. Town Lake Index scores by year over time.

Conclusions

As demonstrated, it is possible to construct an indexing system that can track changes to Town Lake over time using a variety of data sources unique to Town Lake that is simple to communicate to the public or decision makers. Based on the components and weights selected, the Town Lake Index yields an average value of "good" according to the comparable EII narrative score classification.

Recommendations

Policy decision makers should carefully review the component weighting to insure that the included components accurately reflect their relative public importance. Water and sediment quality component calculation methods were chosen to facilitate direct comparison to creek values generated for the EII. While applicable, creeks q-curve breakpoint values and the list of included parameters for the sediment and water quality components may not be the most appropriate for Town Lake system.

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